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FINAL REPORT

DEVELOPMENT OF LOW COST ABLATIVE NOZZLES FOR SOLID PROPELLANT ROCKET MOTORS

VOLUME II

by

J. R. Mathis and R. C. Laramee

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION
Brigham City, Utah

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Cleveland, Ohio
J. J. Notardonato, Project Manager

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J. J. Notardonato, Project Manager

FOREWORD

The research and development work described herein was conducted by Thiokol Chemical Corporation under NASA Contract NAS3-10288. The work was done under the management of the NASA Project Manager, Mr. J. J. Notardonato, NASA-Lewis Research Center.

This program was conducted at the Wasatch Division under the management of Mr. E. L. Bennion with Mr. E. L. Gray as the project engineer. Principal investigators were Mr. J. R. Mathis and Mr. R. C. Laramee. Motor manufacturing was supervised by Mr. L. S. Jones.

The program final report consists of two volumes. Volume I contains the text and Volume II the illustrations and tables as referenced in the text.

ABSTRACT

The object of this program was to investigate and evaluate low cost materials and processes applicable to full sized nozzles for 260 in. solid rockets.

Over 20 materials were subjected to increasingly severe tests, consisting of mechanical, physical, and thermal properties and evaluation in nozzles of three different sizes, ranging in throat diameter from 0.34 to 8.1 inches. Resulting data were analyzed, and the better performing materials were employed in the design and performance prediction of four full sized nozzles for 260 in. solid rockets.

Conclusions are that acceptable full sized nozzles can be fabricated at substantially lower cost than those produced in the past.

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TABLE 1

VENDORS CONTACTED

1. Armour Coated Products and Adhesives Co.
   Standard Insulation Division
   Saugus, California

2. Coast Manufacturing and Supply Co.
   Livermore, California

3. Hooker Chemical Corporation
   Durez Plastics Division
   Los Angeles, California

4. Fiberite Corporation
   Orange, California

5. Whittaker Corporation
   Narmco Materials Division
   Costa Mesa, California

6. Raybestos-Manhattan, Inc.
   Manheim, Pennsylvania

7. U.S. Polymeric, Inc.
   Santa Ana, California

8. Ferro Corporation
   Cordo Division
   Culver City, California

9. Johns-Manville Sales Corporation
   Aerospace Products Dept
   Los Angeles, California

10. Minnesota Mining and Mfg Co.
    St. Paul, Minnesota

11. IIT Research Institute
    Chicago, Illinois

TABLE 2

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL	POTENTIAL USE	REMARKS
LOW COST CARBONA-CEOUS	LCCM-2610*	THIOKOL	GRAPHITE POWDER PHENOLIC, MOLDING COMPOUND GRAPHITE PARTICLES 75% SC-1008 RESIN 25%	TENSILE 2,900 PSI ELONGATION 0.23% COMPRESSIVE 12,000 PSI DENSITY 1.7 GM/CC COMP. MOD. 4.5 X 10^5 PSI THERMAL COND. 0.41 BTU/FT-HR°F	COMPRESSION MOLD AT 1,000 PSI AND 300°F	1. TU-379 MOTOR EXIT CONE 0.14 mils/sec THROAT 0.2 mils/sec ADAPTER mils/sec 2. CHAR MOTOR (D_t = 3.8) THROAT = 0 mils/sec FWD EXIT CONE = (1 mils/sec)	0.54/LB DEV. MATERIAL EASILY PRODUCED	THROAT INLET EXIT CONE	LOW MATERIALS COST WITH EXCELLENT EROSION RESISTANCE
LOW COST CARBONA-CEOUS	LCCM-4113*	THIOKOL	GRAPHITE PARTICLE-NBR PHENOLIC CASTING COMPOUND GRAPHITE PARTICLES 75% SC-1008 RESIN 12.5% HITCO 158 12.5%	TENSILE 440 PSI ELONGATION 5.2% COMPRESSIVE, ULT. 130 PSI MODULUS 6.7 X 10^3 PSI DENSITY 1.3 GM/CC THERMAL COND. 0.66 BTU/FT. -HR. °F	TROWEL AND CURE AT 15 PSI AND 170°F	1. TU-379 MOTOR ADAPTER 3.9 mils/sec 2. CHAR MOTOR INLET = 3 mils/sec BACKUP-OK	0.50/LB DEV. MATERIAL EASILY PRODUCED	BACKUP INLET CAP	LOW MATERIAL COST RELATIVELY FLEXIBLE EXTENSIVE CURING FACILITIES NOT REQ'D
LOW COST CARBONA-CEOUS	LCCM-4120*	THIOKOL	GRAPHITE PARTICLE-PHENOLIC CASTING OR MOLDING COMPOUND GRAPHITE PARTICLES 75% DUREZ 10694 RESIN 25%	TENSILE 2,300 PSI ELONGATION 0 15% COMPRESSIVE, ULT. 8,200 PSI MODULUS 4.6 X 10^5 DENSITY 1.6 GM/CC THERMAL COND. 0 89 BTU/FT. -HR. °F	CAST AND CURE AT 15 PSI AND 170°F	1. TU-379 MOTOR THROAT 0.6 mils/sec EXIT CONE 0.2 mils/sec 2. CHAR MOTOR BACKUP-OK AFT EXIT = 0.5 mils/sec EXIT CONE = 1.5 mils/sec	0.50/LB DEV. MATERIAL EASILY PRODUCED	THROAT EXIT CONE INLET	LOW MATERIAL COST CURING FACILITIES NOT REQ'D. POTENTIALLY A GOOD THROAT MATERIAL
LOW COST CARBONA-CEOUS	LCCM-(Reinforced)*	THIOKOL	GRAPHITE PARTICLE-PHENOLIC+ASBESTOS, GLASS, RAYON, OR CARBON FIBERS				1.00-10.00/LB EASILY PRODUCED OFF-THE-SHELF RAW MATERIALS		RELATIVELY LOW MATERIALS COST WITH IMPROVED MECH. PROPERTIES. HANDLING AND CURING CHARACTER-ISTICS RELATIVELY SIMPLE.
LOW COST CARBONA-CEOUS	LCCM-(Microballoon)	THIOKOL	GRAPHITE PARTICLE-PHENOLIC+GLASS, SILICA OR PHENOLIC MICROBALLOONS				0.75-1.50/LB EASILY PRODUCED OFF-THE-SHELF RAW MATERIALS		LOW COST, LOW DENSITY
LOW COST CARBONA-CEOUS	D-1	ATLANTIC RESEARCH CORP.	COKE FILLED-ACID CATALYZED FURFURYL ALCOHOL CASTING COMP. UNGROUND COKE 49.2% GROUND COKE 16.4% PETROLEUM COKE 16.4% BINDER 18%	COMPRESSIVE, ULT. 10,000 PSI		AFRPL MOTORS - PER-FORMED ADEQUATELY (REPORT NO. AFRPL-TR-66-111)	UNKNOWN	BACKUP	POTENTIALLY A GOOD BACKUP MATERIAL. LONG, SLOW CURE REQ'D.

*MATERIALS RECOMMENDED FOR USE IN EVALUATION PHASE OF PROGRAM

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
LOW COST CARBON CLOTH BINDER	SP-8050* SP-8050-2	ARMOUR COATED PRODUCTS	CARBON CLOTH-PHENOLIC (-2 IS DOUBLE THICKNESS) EVERCOAT EC-201 33%	COMPRESSIVE, ULT. 34,500 PSI MOD. 2.4 X 10^6 PSI TENSILE, ULT. 9,100 PSI MOD. 2.5 X 10^6 PSI SPECIFIC GRAVITY 1.47	TAPE WRAP AND HYDRO-CLAVE CURE AT 325°F AND 250+PSI	NOMAD NOZZLE PRO-GRAM-AFTER 1st SEVEN FIRINGS, SP-8050 RECOMMEND-ED FOR THROAT EXTENSION (FWD EXIT CONE) EROSION = 1.7 mils/sec CHAR = 6.8 mils/sec	17.00-18.50/LB COMMERCIALLY AVAILABLE	FWD EXIT CONE OR THROAT EXTENSION THROAT	A GOOD PERFORMER AT RELATIVELY LOW COST
LOW COST CARBON CLOTH BINDER	4C-1031	COAST MFG AND SUPPLY CO.	CARBON CLOTH-PHENOLIC RESIN 33% REINFORCEMENT 57-61% FILLER 6-10%	SPECIFIC GRAVITY 1.455 SPECIFIC HEAT 0.2406 AT 100°C 0.2622 AT 200°C TENSILE, ULT. 18,000 PSI MOD. 2.3 X 10^6 PSI COMPRESSIVE, ULT. 38,000 PSI	TAPE WRAP AND AUTO-CLAVE CURE AT 325°F AND 200 PSI	NOMAD NOZZLE PRO-GRAM-RECOMMENDED FOR ENTRANCE CAP OR THROAT INLET EROSION = 7.1 mils/sec CHAR = 7.9 mils/sec	20 50/LB COMMERCIALLY AVAILABLE	ENTRANCE CAP OR INLET	
LOW COST CARBON CLOTH BINDER	FM-5059	U.S. POLYMERIC	CARBON CLOTH-PHENOLIC	COMPRESSIVE, ULT. 28,000 PSI MOD. 2.3 X 10^6 PSI TENSILE, ULT. 3,700 PSI MOD. 1.57 X 10^6 PSI SPECIFIC GRAVITY 1.48 SPECIFIC HEAT: 0.2935 AT 100°C 0 3276 AT 200°C	DIE MOLD AT 325°F AND 500 PSI ADAPTABLE TO HYDROCLAVE	NOMAD NOZZLE PRO-GRAM-RECOMMENDED FOR ENTRANCE CAP EROSION = 3.7 mils/sec CHAR = 7.9 mils/sec	17.12/LB COMMERCIALLY AVAILABLE	ENTRANCE CAP	REQUIRES RELATIVELY HIGH PRESSURE CURE
LOW COST CARBON CLOTH BINDER	WB-8217*	FERRO CORP. CORDO DIV.	CARBON CLOTH-PHENOLIC	COMPRESSIVE, ULT. 27,000 PSI MOD. 1.99 X 10^6 PSI TENSILE, ULT. 7,700 PSI MOD. 1.99 X 10^6 PSI SPECIFIC GRAVITY 1.41 SPECIFIC HEAT: 0.2222 AT 100°C 0 2472 AT 200°C	TAPE WRAP AND HYDRO-CLAVE CURE AT 300°F AND 250 PSI	NOMAD NOZZLE PRO-GRAM-RECOMMENDED FOR THROAT THROAT: EROSION = 6.4 mils/sec CHAR = 7.6 mils/sec INLET: EROSION = 10.2 mils/sec CHAR = 5.5 mils/sec	20.97/LB COMMERCIALLY AVAILABLE	THROAT OR INLET	
LOW COST CARBON CLOTH BINDER	MXC-198*	FIBERITE CORP.	CARBON CLOTH-EPOXY NOVOLAC		TAPE WRAP-VACUUM BAG CURE	NO FIRING EXPER.	21.50/LB NEW MATERIAL NO PRODUCTION PROBLEMS FORESEEN	THROAT OR INLET	VERY LOW PRESSURE CURING SYSTEM REQUIRING ONLY VACCUM BAG AND OVEN. HAS GOOD POTENTIAL
LOW COST CARBON CLOTH BINDER	MXC-1600	FIBERITE CORP.	CARBON CLOTH-PHENOLIC (DOUBLE THICKNESS FABRIC)		TAPE WRAP	NO FIRING EXPER.	17.50/LB NEW MATERIAL	ENTRANCE CAP, INLET THROAT	DOUBLE THICKNESS TAPE RESULTING IN LOW FAB. TIME.

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
LOW COST CARBONA-CEOUS	D-13	ATLANTIC RESEARCH CORP.	COKE FILLED-ACID CATA-LYZED FURFURYL ALCOHOL CASTING COMPOUND UNGROUND COKE 49.8% GROUND COKE 16.6% PETROLEUM COKE 16.6% BINDER 17.0%			AFRPL MOTORS - IN CONCLUSIVE RESULTS	UNKNOWN	INLET	MAY REQUIRE ADDITIONAL DEVELOPMENTS
FIBER PAPER PHENOLIC	MXC-113* (MXC-313)	FIBERITE CORP.	CARBON FIBER PAPER PHENOLIC	COMPRESSIVE, ULT. 10,600 PSI TENSILE, ULT, 7,900 PSI MOD. 0.94 X 10^6 PSI ELONGATION 0.96% FLEXURAL, ULT. 12,400 PSI SPECIFIC GRAVITY 1.05	TAPE WRAP AND CURE IN HYDROCLAVE OR AUTO-CLAVE AS LOW AS 25 PSI. DENSITY CONTROLLED BY TAPE TENSION, HEAD PRESSURE AND CURE PRESSURE	NOMAD NOZZLE NO. 4-ENTRANCE CAP-AC-CEPTABLE PERFORM-ANCE-8 7 mils/sec TU-379 1.4 mils/sec NOMAD NO. 1, 3.4 mils/sec NOMAD NO. 6, 13 mils/sec	14.50 /LB COMMERCIALLY AVAILABLE	BACKUP FWD EXIT CONE INLET	LOWER COST, LOWER DENSITY, LOWER FAB COSTS. DENSITY MAY BE VARIED SOMEWHAT. SOME DEV. OF FAB. TECHNIQUES REQ'D. GOOD POTENTIAL
FIBER PAPER PHENOLIC	MXS-113* (MXS-313)	FIBERITE CORP.	SILICA FIBER PAPER PHENOLIC		SAME AS FOR MXC-113		4.75 /LB COMMERCIALLY AVAILABLE	BACKUP AFT EXIT CONE	SAME AS FOR MXC-113
FIBER PAPER PHENOLIC	MXA-113* (MXA-313)	FIBERITE CORP.	ASBESTOS FIBER PAPER PHENOLIC		SAME AS FOR MXC-113		1.80/LB COMMERCIALLY AVAILABLE	BACKUP AFT EXIT CONE	SAME AS FOR MXC-113
FIBER PAPER PHENOLIC	MXCS-313	FIBERITE CORP.	CARBON-SILICA FIBER PAPER PHENOLIC		SAME AS FOR MXC-113		9.75/LB COMMERCIALLY AVAILABLE	EXIT CONE	SAME AS FOR MXC-113. INTENDED TO BE USED IN TRAN-SITION AREA FROM HIGH EROSION (MXC-113) TO LOW EROSION (MXS-113) AREAS OF EXIT CONE. COST SAVINGS WOULD RESULT.
FIBER PAPER PHENOLIC	MXSA-313	FIBERITE CORP.	SILICA-ASBESTOS FIBER PAPER PHENOLIC		SAME AS FOR MXC-113		3.25/LB COMMERCIALLY AVAILABLE	EXIT CONE	SAME AS FOR MXC-113. INTENDED TO BE USED IN TRAN-SITION AREA FROM MEDIUM EROSION (MXS-113) TO LOW EROSION (MSA-113) AREAS OF EXIT CONE. COST SAVINGS WOULD RESULT ENTIRE 113 AND 313 SERIES FEATURE "TAPERED DENSITY" CAPABIL-ITY IN EXIT CONE.

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
LOW COST CARBON CLOTH BINDER	FM-5511	U.S. POLYMERIC	CARBON CLOTH-PHENOLIC	TENSILE, ULT. 14,000 PSI MOD. 1.9×10^6 PSI COMPRESSIVE, ULT. 18,000 PSI MOD. 1.5×10^6 PSI FLEXURAL, ULT. 23,500 PSI MOD. 1.6×10^6 PSI SPECIFIC GRAVITY, 1.51	TAPE WRAP AND CURE AT 325°F AND 1,000 PSI	NO FIRING EXPER.	20.00/LB COMMERCIALLY AVAILABLE	INLET, FWD EXIT CONE, THROAT EXTENSION	
LOW COST CARBON CLOTH BINDER	4C-1831	COAST MFG. AND SUPPLY	CARBON CLOTH-PHENOLIC (DOUBLE THICKNESS FABRIC) RESIN 33% REINFORCEMENT 57-61% FILLER 6-10%	TENSILE, ULT. 22,500 PSI MOD. 1.7×10^6 PSI COMPRESSIVE, ULT. 31,000 PSI SPECIFIC GRAVITY, 1.35 SPECIFIC HEAT, 0.3384 AT 200°C THERMAL DIFFUSIVITY· 0.0038 AT R.T. 0.0048 AT 100°C AND 200°C	TAPE WRAP AND CURE AT 350°F AND 250 PSI	NOMAD NOZZLE NO. 4 THROAT EXTENSION EROSION = 5.3 mils/sec CHAR = 2.9 mils/sec	20.50/LB COMMERCIALLY AVAILABLE	INLET, FWD EXIT CONE, THROAT EXTENSION	DOUBLE THICKNESS FABRIC PROVIDES DECREASED WRAP TIME
LOW COST CARBON CLOTH BINDER	4C-1686*	COAST MFG. AND SUPPLY	CARBON CLOTH-POLY-PHENYLENE RESIN 33% REINFORCEMENT 57-61% FILLER 6-10%	TENSILE, ULT. 25,000 PSI MOD. 2.5×10^6 PSI COMPRESSIVE, ULT. 30,000 PSI SPECIFIC GRAVITY, 1.40	TAPE WRAP AND CURE AT 350°F AND 250 PSI	NOMAD NOZZLE NO. 11-THROAT	20.60/LB COMMERCIALLY AVAILABLE	INLET, FWD EXIT CONE, THROAT, THROAT EXTENSION, CAP	POTENTIAL IMPROVEMENT IN PERFORMANCE THROUGH SUPERIOR CHAR CHARACTERISTICS OF POLYPHENYLENE SYSTEM.
LOW COST CARBON CLOTH BINDER	FM-5072 LD*	U.S. POLYMERIC	CARBON CLOTH-PHENOLIC (with Silica Microballoons)	COMPRESSIVE, ULT. 16,400 PSI MOD. 1.39×10^6 PSI TENSILE, ULT. 7,800 PSI MOD. 1.96×10^6 PSI SPECIFIC GRAVITY, 1.31 SPECIFIC HEAT, 0.2279 THERMAL DIFFUSIVITY AT R.T.· 0.0026 cm^2/sec	TAPE WRAP AND CURE AT 300°F AND 200 PSI MAX	NOMAD NOZZLE NO 3 (THROAT EXTENSION) EROSION = 2 mils/sec CHAR = 5.7 mils/sec NOMAD NOZZLE NO. 6 (INLET) EROSION = 14.5 mils/sec CHAR = 4.8 mils/sec	23.25/LB COMMERCIALLY AVAILABLE	THROAT, THROAT EXTENSION ENTRANCE CAP	
LOW COST CARBON CLOTH BINDER	4037	NARMCO	CARBON CLOTH-PHENOLIC RESIN (NARMCO 506) REINFORCEMENT FILLER 8%	COMPRESSIVE, ULT. 32,000 PSI TENSILE, ULT. 17,000 PSI FLEXURE, ULT. 30,000 PSI MOD. 2.5×10^6 PSI SPECIFIC HEAT, 0.25 SPECIFIC GRAVITY, 1.48	TAPE WRAP AND CURE AT 300°-350°F AND 200-1,000 PSI	NO FIRING EXPERIENCE		INLET, THROAT, THROAT EXTENSION	AVAILABLE IN SINGLE OR DOUBLE THICKNESS TAPE

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
LOW COST SILICA CLOTH BINDER	MX-2600-96	FIBERITE CORP.	SILICA CLOTH-PHENOLIC (DOUBLE THICKNESS FABRIC)	SPECIFIC HEAT 0.2181 AT 100°C 0.2838 AT 200°C DENSITY, 1 60 G/CM^3	TAPE WRAP AND HYDRO-CLAVE CURE AT 325°F AT 1,000 PSI	NOMAD NOZZLES NO 2, 3, 6, USED AS THROAT OVERWRAP. NO COMMENTS MADE ON PERFORMANCE, ASSUMED TO BE GOOD	5.20/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE, BACKUP	DOUBLE THICKNESS TAPE PROVIDES DECREASED FAB. TIME.
LOW COST SILICA CLOTH BINDER	MXS-198*	FIBERITE CORP.	SILICA CLOTH-EPOXY NOVOLAC		TAPE WRAP AND OVEN CURE AT 15 PSI	NO FIRING EXPER.	6.10/LB NEW MATERIAL NO PRODUCTION PROBLEMS ANTICIPATED	AFT EXIT CONE	WILL CURE IN OVEN UNDER VACUUM BAG PRESSURE-VERY LOW COST PROCESS
LOW COST SILICA CLOTH BINDER	SP-8030-96* -48*	ARMOUR	SILICA CLOTH-PHENOLIC (DOUBLE THICKNESS FABRIC) SINGLE THICKNESS FABRIC	COMPRESSIVE, ULT. 22,000 PSI MOD. 2.61 X 10^6 PSI TENSILE ULT. 10,000 PSI MOD. 2.48 X 10^6 PSI SPECIFIC GRAVITY 1 70	TAPE WRAP AND CURE AT 300°F AND 225 PSI	NOMAD NOZZLE PROGRAM NOZZLE NO. 1 THROAT APPROACH EROSION 6.4 mils/sec CHAR 3.5 mils/sec NOZZLE NO. 2, THROAT APPROACH EROSION 4.8 mils/sec CHAR 3.4 mils/sec NOZZLE NO. 4-EXIT EXTENSION (SP-8030-48) EROSION 5.7 mils/sec CHAR 2.4 mils/sec	4.75/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE, THROAT APPROACH	LOWER RAW MATERIAL COST DOUBLE THICKNESS TAPE PROVIDES DECREASED FABRICATION TIME
LOW COST SILICA CLOTH BINDER	FM-5504 LD	U.S. POLYMERIC	SILICA CLOTH-PHENOLIC WITH MICROBALLOONS ADDED	SPECIFIC GRAVITY, 1.00 TENSILE, ULT. 5,500 PSI MOD. 1.15 X 10^6 PSI COMPRESSIVE, ULT. 18,000 PSI MOD. 1.15 X 10^6 PSI FLEXURAL, ULT 9,000 PSI MOD. 1 12 X 10^6 PSI	TAPE WRAP AND CURE AT 300°F AND 200 PSI MAX				SPECIFIC GRAVITY MAY BE VARIED FROM 0.80 - 1.20
LOW COST SILICA CLOTH BINDER	4S-5132	COAST MFG AND SUPPLY	SILICA CLOTH-PHENOLIC (DOUBLE THICKNESS FABRIC) RESIN REINFORCEMENT FILLER	TENSILE, ULT. 15,000 PSI MOD. 2.2 X 10^6 PSI COMPRESSIVE, ULT. 20,000 PSI SPECIFIC GRAVITY, 1.70	TAPE WRAP AND CURE AT 300°F AND 250 PSI		5.10/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE, BACKUP THROAT APPROACH	DOUBLE THICKNESS TAPE PROVIDES DECREASED FABRICATION TIME
LOW COST SILICA CLOTH BINDER	4S-5186*	COAST MFG. AND SUPPLY	SILICA CLOTH-POLYPHENYLENE (DOUBLE THICKNESS FABRIC)	TENSILE, ULT. 16,000 PSI MOD. 2.7 X 10^6 PSI COMPRESSIVE, ULT. 20,000 PSI SPECIFIC GRAVITY, 1 70	TAPE WRAP		5.25/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE	POTENTIAL IMPROVED PERFORMANCE THROUGH SUPERIOR CHAR CHARACTERISTICS OF POLYPHENYLENE SYSTEM
LOW COST SILICA CLOTH BINDER	4065*	NARMCO	SILICA CLOTH-NBR PHENOLIC (WITH ORGANIC SPHERES)	COMPRESSIVE, ULT. 2,100 PSI TENSILE, ULT. 2,000 PSI FLEXURE, ULT. 5,100 PSI SPECIFIC GRAVITY, 0.65 SPECIFIC HEAT, 0 30	TAPE WRAP AND CURE AT 325°F AND 15 PSI		COMMERCIALLY AVAILABLE	BACKUP	LIGHTWEIGHT MATERIAL REQUIRING ONLY VACUUM BAG CURE

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
ASBESTOS BINDER	MXA-6012*	FIBERITE CORP.	ASBESTOS-PHENOLIC (CROCIDOLITE)	COMPRESSIVE, ULT. 22,000 PSI MOD. 1.1 X 10^6 PSI TENSILE, ULT. 10,000 PSI MOD. 1.59 X 10^6 PSI SPECIFIC GRAVITY, 1.60 SPECIFIC HEAT 0.2181 AT 100°C 0 2838 AT 200°C THERMAL DIFFUSIVITY- 0 0013 AT 100°C AT 200°C	TAPE WRAP-CURE AT 300°F AND 225 PSI	NOMAD NOZZLE PROGRAM-NOZZLE NO. 1 THROAT OVERWRAP - NO PERFORMANCE DATA NOZZLE NO. 2- EXIT EXTENSION EROSION, 6.2 mils/sec CHAR, 1.7 mils/sec NOZZLES NO. 3 AND 4- THROAT APPROACH EROSION, 5.1 AND 5.7 mils/sec CHAR, 3 AND 2.1 mils/sec	1.85/LB COMMERCIALLY AVAILABLE	EXIT CONE, OVERWRAP, INLET, APPROACH	RELATIVELY THICK TAPE (0.014-0 015) ALLOWS FOR LOWER WRAP TIME
ASBESTOS BINDER	MXA-198	FIBERITE CORP.	ASBESTOS FABRIC-EPOXY NOVOLAC		TAPE WRAP AND CURE UNDER VACUUM BAG IN OVEN	NO FIRING EXPERIENCE	2.00/LB NEW MATERIAL, NO PRODUCTION PROBLEMS ANTICIPATED	AFT EXIT CONE, OVERWRAP, THROAT APPROACH	VERY LOW COST FACILITIES REQ'D VACUUM BAG AND OVEN
ASBESTOS BINDER	WBC-7201	CORDO DIV. FERRO CORP.	ASBESTOS-PHENOLIC (WITH SILICA MICRO-BALLOONS)					AFT EXIT CONE, OVERWRAP	
ASBESTOS BINDER	FM-5525	U.S. POLYMERIC	ASBESTOS-PHENOLIC (CROCIDOLITE)	COMPRESSIVE, ULT. 7,000 PSI MOD. 1.55 X 10^6 PSI TENSILE, ULT. 16,000 PSI MOD 2.88 X 10^6 PSI SPECIFIC GRAVITY, 1.68 SPECIFIC HEAT: 0.2163 AT 100°C 0.2533 AT 200°C	TAPE WRAP-CURE AT 300°F AND 230 PSI	NOMAD NOZZLE PROGRAM-SATISFACTORY PERFORMANCE NOZZLE NO. 3-EXIT EXTENSION EROSION, 6.6 mils/sec CHAR, 1.5 mils/sec NOZZLE NO. 4, THROAT OVERWRAP NO DATA REPORTED	2.00/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE, OVERWRAP	
ASBESTOS BINDER	4A-6385*	COAST MFG. AND SUPPLY	ASBESTOS-POLYPHENYLENE (with Ceramic Microballoons) RESIN 50% REINFORCEMENT 50%	COMPRESSIVE, ULT. 23,000 PSI TENSILE, ULT. 6,400 PSI MOD. 1.06 X 10^6 PSI ELONGATION, 0.8% FLEXURAL, ULT. 17,800 PSI SPECIFIC GRAVITY, 1.40	TAPE WRAP-CURE AT 325°F AND 25 PSI	TU-379, RESULTS INCONCLUSIVE	3.50/LB COMMERCIALLY AVAILABLE	AFT EXIT CONE, OVERWRAP	
ASBESTOS BINDER	22-RPD	RAYBESTOS MANHATTAN	CHRYSOTILE ASBESTOS-PHENOLIC (with Ceramic Filler)	TENSILE, ULT. 13,200 PSI MOD. 2.15 X 10^6 PSI FLEXURE, ULT. 15,700 PSI MOD. 1.78 X 10^6 PSI COMPRESSION, ULT. 6,800 PSI	TAPE WRAP AND CURE AT 300°F AND 50 PSI		4.25/LB COMMERCIALLY AVAILABLE	BACKUP	
ASBESTOS BINDER	23-RPD*			MOD. 1.28 X 10^6 PSI SPECIFIC GRAVITY, 1.11					
ASBESTOS BINDER	MICROBESTOS DS -PHENOLIC*	JOHNS-MANVILLE ASBESTOS-IMPREGNATOR NOT YET KNOWN	CHRYSOTILE ASBESTOS-PHENOLIC (With Cork Filler)		TAPE WRAP AND CURE AT 300°F AND 50 PSI	NO FIRING EXPERIENCE	4 25/LB COMMERCIALLY AVAILABLE	BACKUP	

TABLE 2. -Continued

CANDIDATE NOZZLE MATERIALS

FAMILY	DESIGNATION	SUPPLIER	MATERIAL DESCRIPTION	MECH. PROPERTIES AT 75°F	PROCESSING INFORMATION	FIRING EXPERIENCE	COST AND AVAIL.	POTENTIAL USE	REMARKS
PAPER BINDER	SMS-21	THIOKOL	KRAFT PAPER-PHENOLIC	COMPRESSIVE, ULT. 36,000 PSI TENSILE, ULT. 22,000 PSI MOD. 1.66 X 10^6 PSI ELONGATION, 1.9% FLEXURAL, ULT. 21,000 PSI SPECIFIC GRAVITY, 1.22	TAPE WRAP-CURE AT 325°F AND 25 PSI	TU-379, RESULTS INCONCLUSIVE	1.20/LB COMMERCIALLY AVAILABLE	BACKUP	LOW COST, WILL REQUIRE SOME DEVELOPMENT OF FAB. TECHNIQUES. APPARENT LOW CHAR STRENGTH
PAPER BINDER	FM-5272*	U.S. POLYMERIC	KRAFT CREPE PAPER-PHENOLIC	SPECIFIC HEAT. 0.372 AT 200°C SPECIFIC GRAVITY, 1.33 TENSILE, ULT. 7,400 PSI MOD. 0.9 X10^6 PSI FLEXURAL, ULT. 11,400 PSI MOD. 0.94 X 10^6 PSI	TAPE WRAP AND CURE AT 325°F AND 150 PSI	NOMAD NOZZLE NO. 7 THROAT APPROACH EROSION, 2.9 mils/sec CHAR, 2.4 mils/sec	2.00/LB COMMERCIALLY AVAILABLE	BACKUP, THROAT APPROACH	
PAPER BINDER	MXP-1	FIBERITE CORP.	KRAFT PAPER-PHENOLIC		TAPE WRAP			BACKUP	
OTHER SYSTEMS	V-44	GENERAL TIRE AND RUBBER	ASBESTOS AND SILICA FILLED-NBR		LAYUP AND CURE IN OVEN AT 300°F UNDER VACUUM BAG	NOMAD NOZZLE NO. 5- THROAT APPROACH EROSION, 14.1 mils/sec CHAR, 0.1 mils/sec FIRED IN FULL SPECTRUM OF THIOKOL MOTORS, NORMALLY AS CASE INSULATION, PERFORMANCE HAS GENERALLY BEEN GOOD.	3.19/LB COMMERCIALLY AVAILABLE	THROAT APPROACH	
	KF-418*	FIBERITE CORP.	CANVAS DUCK-PHENOLIC	COMPRESSIVE, ULT. 20,300 PSI MOD. 0.81 X 10^6 PSI TENSILE, ULT. 8,200 PSI MOD. 0.73 X 10^6 PSI SPECIFIC GRAVITY, 1.33 SPECIFIC HEAT. 0.3443 AT 100°C 0.3642 AT 200°C	TAPE WRAP AND CURE AT 300°F AND 225 PSI	NOMAD NOZZLE NO. 6- EXIT EXTENSION EROSION, 5 mils/sec CHAR, 3 mils/sec NOMAD NOZZLE NO. 8, EXIT CONE EROSION, 12 mils/sec (AFT OF THROAT) CHAR, 1.7 mils/sec NOMAD NOZZLE NO. 8, THROAT APPROACH EROSION, 4.7 mils/sec CHAR, 4.7 mils/sec	1.50/LB COMMERCIALLY AVAILABLE	THROAT APPROACH EXIT EXTENSION BACKUP	

TABLE 3

THIOKOL MATERIAL RECOMMENDATIONS

Material	Type	Supplier
LCCM-2610	Graphite particle phenolic	Thiokol Chemical Corporation
LCCM-4113	Graphite particle NBR phenolic	Thiokol Chemical Corporation
LCCM-4120	Graphite particle phenolic	Thiokol Chemical Corporation
LCCM- (reinforced)	Graphite particle phenolic, reinforced	Thiokol Chemical Corporation
MXC-113	Carbon fiberpaper phenolic	Fiberite Corporation
MXS-113	Silica fiberpaper phenolic	Fiberite Corporation
MXC-198	Carbon cloth epoxy novolac	Fiberite Corporation
MXA-6012	Crocidolite asbestos phenolic	Fiberite Corporation
KF-418	Canvas phenolic	Fiberite Corporation
MXS-198	Silica cloth epoxy novolac	Fiberite Corporation
SP-8030-48	Silica cloth phenolic	Armour Coated Products
SP-8030-96	Heavyweight silica cloth phenolic	Armour Coated Products
SP-8050	Carbon cloth phenolic	Armour Coated Products
4C-1686	Carbon cloth polyphenylene	Coast Mfg & Supply
4S-5186	Silica cloth polyphenylene	Coast Mfg & Supply
4A-6385	Asbestos polyphenylene (ceramic microballoons)	Coast Mfg & Supply
FM-5072LD	Carbon cloth phenolic (silica microballoons)	U.S. Polymeric
FM-5272	Crepe paper phenolic	U.S. Polymeric
4065	Silica cloth NBR phenolic (silica microballoons)	Narmco Materials
23-RPD	Cork/asbestos phenolic	Raybestos-Manhattan, Inc
WB-8217	Carbon cloth phenolic	Western Backing
WB-7605	Microbestos DS phenolic	Western Backing/ Johns-Manville

TABLE 4

MATERIALS SELECTED FOR SUBSCALE EVALUATION

Material	Type	Nomad Nozzles No.	Supplier
MXC-313	Carbon fibertape phenolic	1, 4, 5, 6	Fiberite Corporation
SP-8050	Carbon cloth phenolic	2	Armour Coated Products
WB-8217	Carbon cloth phenolic	1, 4	Western Backing
MXA-6012	Asbestos phenolic	1, 2, 3, 4	Fiberite
FM-5272	Kraft crepe paper phenolic	7	U.S. Polymeric
KF-418	Canvas phenolic	6, 8	Fiberite Corporation

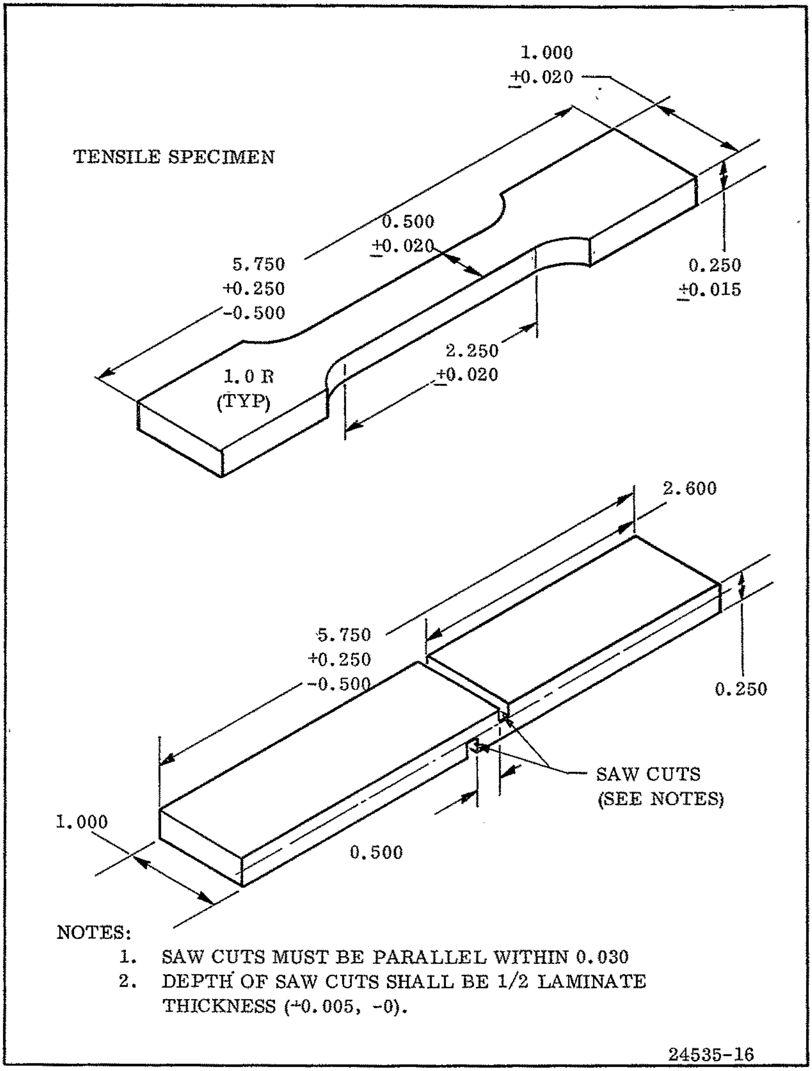


Figure 1 . Tensile and Interlaminar Shear Specimens

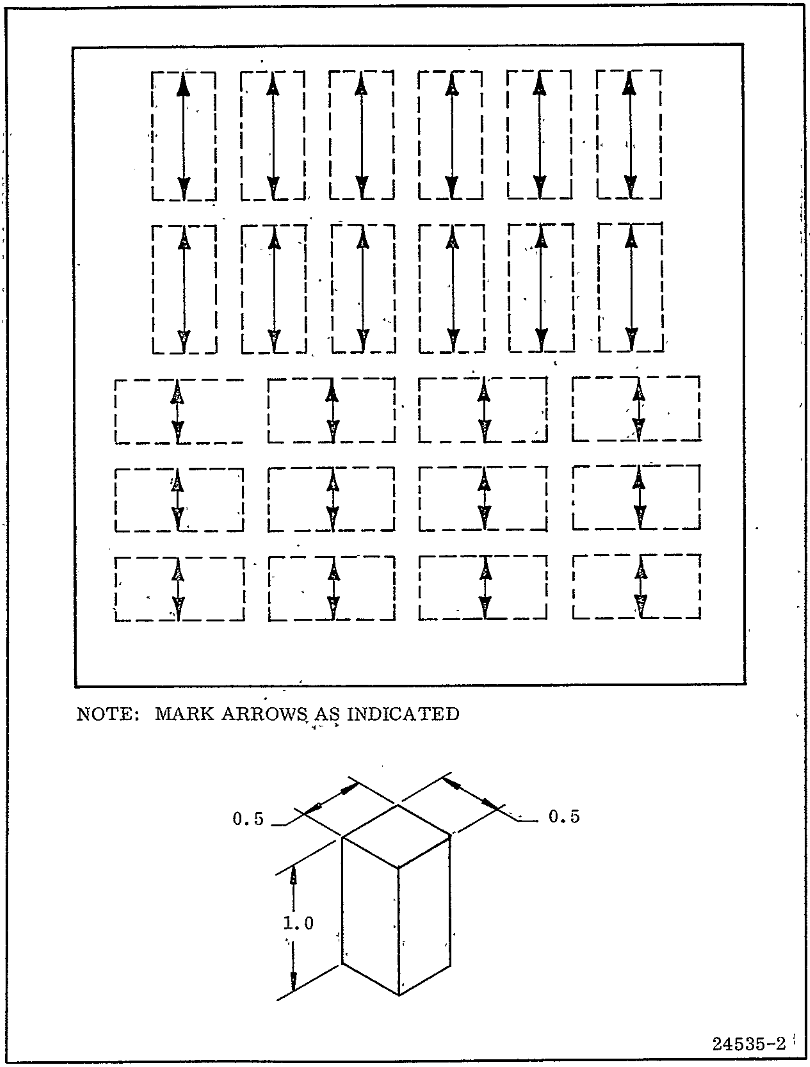


Figure 2 . Compression Test Specimen Cutting Pattern and Configuration

TABLE 5

PHYSICAL AND MECHANICAL PROPERTIES

Physical and Mechanical Properties	LCCM-2610	LCCM-4113	LCCM-4120
THIOKOL LOW COST CARBONACEOUS MATERIALS			
Tensile Strength (psi)			
1. Room Temperature			
Ultimate	2,900	450	2,300
2. 300°F, Ultimate	1,700	80	800
3. 600°F, Ultimate	*	350	150
Compressive Strength (psi)			
1. Room Temperature			
Ultimate	12,000	130	8,200
2. 300°F, Ultimate	5,000	30	2,000
3. 600°F, Ultimate	2,800	800	6,700
Hardness, Shore "D"	81	55	70
Specific Gravity	1.8	1.6	1.5

*Specimens fractured due to excessive gripping pressure.

TABLE 5. - Continued

PHYSICAL AND MECHANICAL PROPERTIES

Physical and Mechanical Properties	MXA-313	MXS-313
FIBERITE FIBER PAPER PHENOLIC MATERIALS		
Tensile Strength (psi)		
A. Parallel		
1. Room Temperature, Ultimate	17,100	6,700
Room Temperature, Modulus	3.19×10^6	1.31×10^6
2. 300°F, Ultimate	9,900	4,800
3. 600°F, Ultimate	1,900	2,600
B. Perpendicular		
1. Room Temperature, Ultimate	15,200	4,100
Room Temperature, Modulus	2.79×10^6	0.81×10^6
2. 300°F, Ultimate	10,800	2,500
3. 600°F, Ultimate	1,800	2,200
Compressive Strength (psi)		
A. Parallel		
1. Room Temperature, Ultimate	18,500	9,600
2. 300°F, Ultimate	14,050	7,900
3. 600°F, Ultimate	8,700	3,900
B. Perpendicular		
1. Room Temperature, Ultimate	17,300	5,500
2. 300°F, Ultimate	13,750	4,700
3. 600°F, Ultimate	8,000	2,000
Interlaminar Shear (psi)		
A. Parallel		
1. Room Temperature, Ultimate	1,270	390
2. 300°F, Ultimate	1,000	310
3. 600°F, Ultimate	850	150
B. Perpendicular		
1. Room Temperature, Ultimate	.,330	260
2. 300°F, Ultimate	940	220
3. 600°F, Ultimate	780	220
Hardness, Shore D	93	66
Specific Gravity	1.6	0.8

TABLE 6

PHYSICAL AND MECHANICAL PROPERTIES OF LOW COST CARBON CLOTH MATERIALS

Supplier	Fiberite	Coast	Coast	US Polymeric	Armour	Western Backing
Physical and Mechanical Properties	MXC-198	4C1686	4C2530	FM5072LD	SP8057	WB8251
Tensile Strength (psi)						
A. Parallel						
1. Room Temperature, Ultimate	8,900	18,300	7,600	9,000	6,500	9,000
Room Temperature, Modulus	1.40×10^6	1.86×10^6	2.53×10^6	1.29×10^6	1.39×10^6	2.54×10^6
2. 300°F, Ultimate	5,100	12,500	3,100	5,600	4,900	5,100
3. 600°F, Ultimate	3,400	10,400	4,500	4,700	4,300	4,400
B. Perpendicular						
1. Room Temperature, Ultimate	9,100	13,600	6,200	4,700	4,900	7,000
Room Temperature, Modulus	1.23×10^6	1.66×10^6	3.30×10^6	1.57×10^6	1.28×10^6	3.15×10^6
2. 300°F, Ultimate	6,100	10,600	3,300	4,500	4,000	3,900
3. 600°F, Ultimate	2,800	13,800	1,900	3,400	3,900	2,900
Compressive Strength (psi)						
A. Parallel						
1. Room Temperature, Ultimate	31,100	13,000	28,100	20,500	28,600	30,200
2. 300°F, Ultimate	18,800	10,900	23,500	8,300	9,200	25,900
3. 600°F, Ultimate	4,000	7,200	8,000	6,100	4,800	5,900
B. Perpendicular						
1. Room Temperature, Ultimate	18,900	14,400	23,900	16,900	27,000	26,700
2. 300°F, Ultimate	11,000	12,100	18,600	6,200	8,300	22,900
3. 600°F, Ultimate	2,500	7,300	5,700	4,900	4,800	4,500
Interlaminar Shear (psi)						
A. Parallel						
1. Room Temperature, Ultimate	780	1,270	760	990	560	650
2. 300°F, Ultimate	570	950	420	580	590	570
3. 600°F, Ultimate	280	880	290	430	N/A	430
B. Perpendicular						
1. Room Temperature, Ultimate	720	1,040	460	870	460	470
2. 300°F, Ultimate	540	870	390	610	580	500
3. 600°F, Ultimate	150	960	210	380	360	370
Hardness, Shore D	84	85	95	91	91	95
Specific Gravity	1.1	1.3	1.5	1.2	1.4	1.5

TABLE 7

PHYSICAL AND MECHANICAL PROPERTIES OF LOW COST SILICA CLOTH MATERIALS

Supplier	Fiberite	Coast	Armour	Narmco
Physical and Mechanical Properties	MXS-198	4S5186	SP-8030-96	4065
Tensile Strength (psi)				
A. Parallel				
1. Room Temperature, Ultimate	10,000	10,800	6,200	6,100
Room Temperature, Modulus	2.61×10^6	2.37×10^6	2.67×10^6	0.89×10^6
2. 300°F, Ultimate	4,500	10,100	4,500	2,800
3. 600°F, Ultimate	2,000	8,300	6,400	2,200
B. Perpendicular				
1. Room Temperature, Ultimate	9,900	10,900	4,200	4,100
Room Temperature, Modulus	2.01×10^6	1.63×10^6	1.79×10^6	0.40×10^6
2. 300°F, Ultimate	4,300	8,700	4,400	1,600
3. 600°F, Ultimate	2,800	5,100	2,800	1,300
Compressive Strength (psi)				
A. Parallel				
1. Room Temperature, Ultimate	34,600	13,600	23,100	6,700
2. 300°F, Ultimate	9,900	12,200	22,900	1,200
3. 600°F, Ultimate	3,600	10,000	10,300	990
B. Perpendicular				
1. Room Temperature, Ultimate	24,000	12,900	27,900	4,200
2. 300°F, Ultimate	7,800	10,400	18,100	920
3. 600°F, Ultimate	2,100	8,400	8,100	620
Interlaminar Shear (psi)				
A. Parallel				
1. Room Temperature, Ultimate	1,250	1,060	600	590
2. 300°F, Ultimate	640	650	550	300
3. 600°F, Ultimate	200	850	610	180
B. Perpendicular				
1. Room Temperature	760	590	390	460
2. 300°F Ultimate	690	550	510	240
3. 600°F, Ultimate	250	550	490	110
Hardness, Shore D	88	92	94	68
Specific Gravity	1.5	1.7	1.6	1.0

TABLE 8

PHYSICAL AND MECHANICAL PROPERTIES OF LOW COST ASBESTOS AND PAPER MATERIALS

Supplier	Coast	Raybestos	Panelyte
Physical and Mechanical Properties	4A6385	23-RPD	SMS-21
Tensile Strength (psi)			
A. Parallel			
1. Room Temperature, Ultimate	17,200	19,700	12,700
Room Temperature, Modulus	2.60×10^6	2.99×10^6	1.52×10^6
2. 300°F, Ultimate	13,100	15,200	6,000
3. 600°F, Ultimate	11,600	8,900	3,500
B. Perpendicular			
1. Room Temperature, Ultimate	10,500	10,800	12,100
Room Temperature, Modulus	1.89×10^6	1.76×10^6	1.38×10^6
2. 300°F, Ultimate	6,600	11,100	6,200
3. 600°F, Ultimate	7,300	7,300	3,000
Compressive Strength (psi)			
A. Parallel			
1. Room Temperature, Ultimate	17,600	15,500	23,400
2. 300°F, Ultimate	12,300	8,300	12,000
3. 600°F, Ultimate	10,000	3,400	2,800
B. Perpendicular			
1. Room Temperature, Ultimate	17,600	13,900	22,400
2. 300°F, Ultimate	12,100	7,700	9,000
3. 600°F, Ultimate	9,200	2,700	1,800
Interlaminar Shear (psi)			
A. Parallel			
1. Room Temperature, Ultimate	1,190	1,700	760
2. 300°F, Ultimate	1,100	1,090	560
3. 600°F, Ultimate	880	1,000	300
B. Perpendicular			
1. Room Temperature, Ultimate	780	1,070	630
2. 300°F, Ultimate	670	720	530
3. 600°F, Ultimate	620	640	330
Hardness, Shore D	92	88	93
Specific Gravity	1.4	1.5	1.3

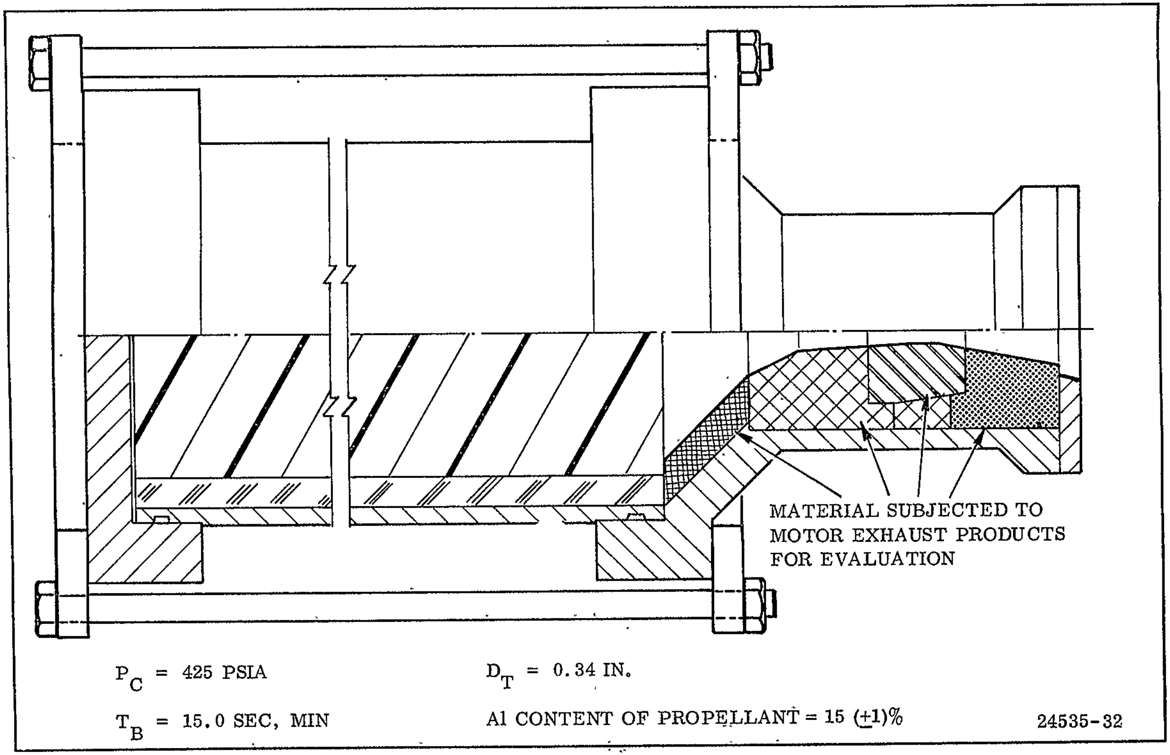


Figure 3 . TU-379 Materials Screening Motor

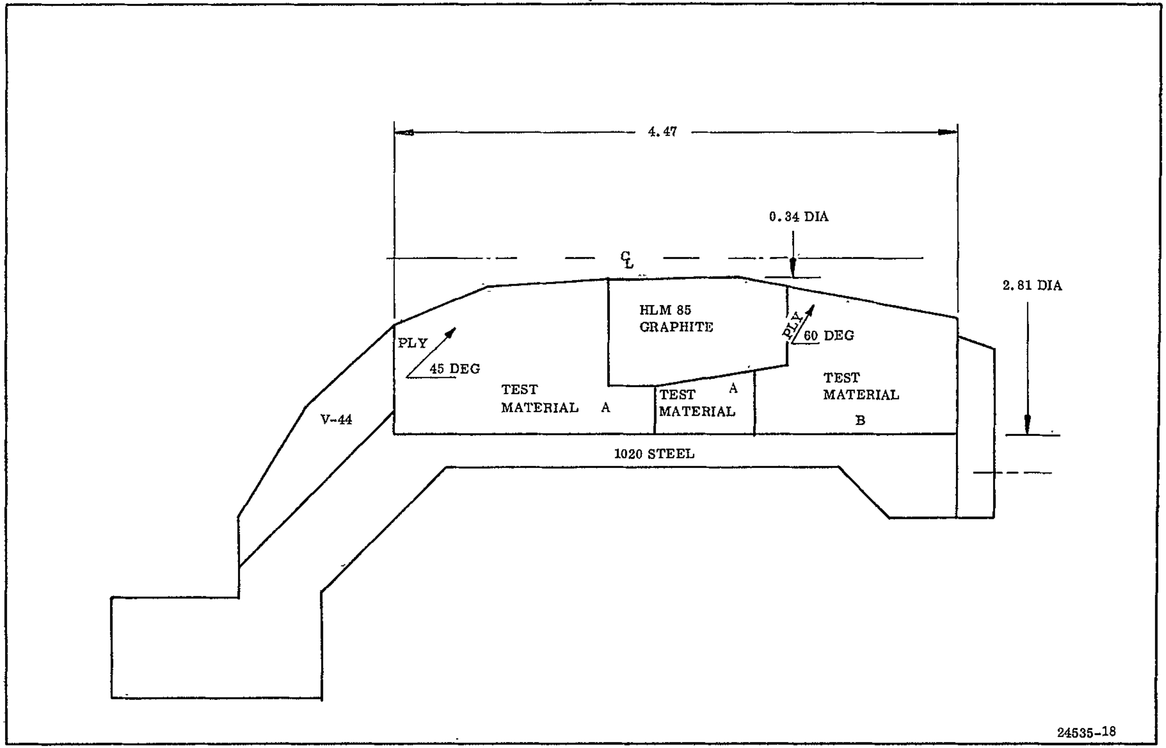


Figure 4 . TU-379 Nozzle

TABLE 9

SUMMARY OF FABRICATION CONDITIONS
TU-379 NOZZLE COMPONENTS

	Material	Curing Conditions
1.	MXA-313 (Asbestos fiberpaper)	100 psi (autoclave) and 320°F
2.	MXS-313 (Silica fiberpaper)	100 psi (autoclave) and 320°F
3.	MXC-198 (Carbon epoxy novolac)	13 psi (vacuum bag) and 310°F
4.	MXS-198 (Silica epoxy novolac)	13 psi (vacuum bag) and 310°F
5.	FM-5072LD (Carbon phenolic)	200 psi (autoclave) and 325°F
6.	4065 (Silica NBR phenolic)	200 psi (autoclave) and 310°F
7.	SP-8030-96 (Silica phenolic)	115 psi (autoclave) and 320°F
8.	SP-8057 (Carbon phenolic)	200 psi (autoclave) and 320°F
9.	4C-1686 (Carbon polyphenylene)	200 psi (autoclave) and 320°F
10.	4C-2530 (Avceram phenolic)	200 psi (autoclave) and 320°F
11.	4S-5186 (Silica polyphenylene)	200 psi (autoclave) and 320°F
12.	4A-6385 (Asbestos polyphenylene)	115 psi (autoclave) and 320°F
13.	WB-8251 (Avceram phenolic)	200 psi (autoclave) and 320°F
14.	23-RPD (Asbestos/cork phenolic)	225 psi (autoclave) and 300°F
15.	SMS-21 (Paper phenolic)	225 psi (autoclave) and 320°F
16.	LCCM-2610 (Graphite phenolic)	1,000 psi (press) and 300°F
17.	LCCM-4120 (Graphite phenolic)	13 psi (vacuum bag) and 300°F
18.	LCCM-4113 (Graphite NBR phenolic)	200 psi (autoclave) and 300°F

MATERIAL

EROSION RATE, MIL/SEC

1. STA 1
2. STA 8
3. STA 9
4. MAXIMUM, STA

CHAR RATE (TYPICAL), MIL/SEC

1.
2.

MOTOR DATA

1. P_{MAX}
2. P_{AVG}
3. t_b

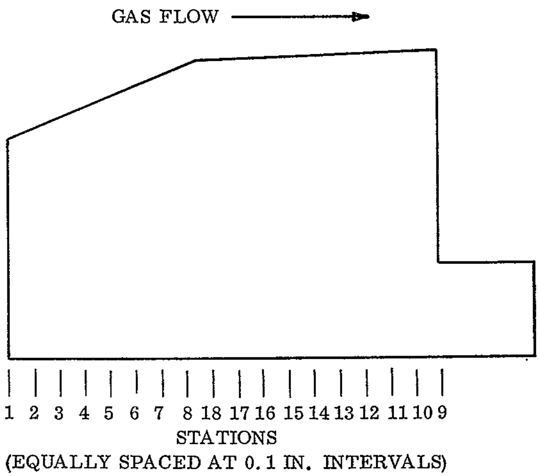


Figure 5. TU-379 Inlet Cone Erosion and Char Profile

MATERIAL

EROSION RATE, MIL/SEC

1. STA 1
2. STA 7
3. STA 14
4. MAXIMUM, STA

CHAR RATE (TYPICAL), MIL/SEC

1. STA
2. STA

MOTOR DATA

1. P_{MAX}
2. P_{AVG}
3. t_b

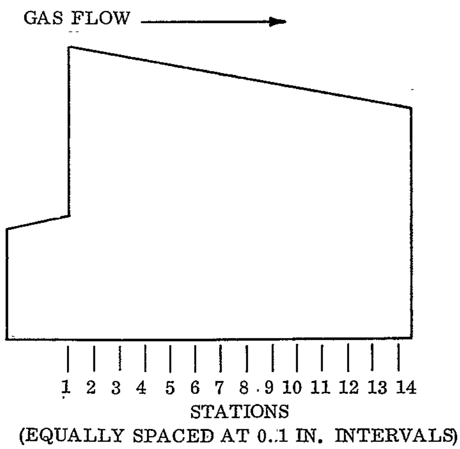
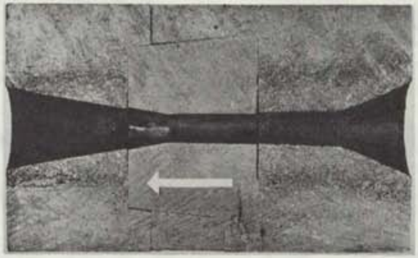


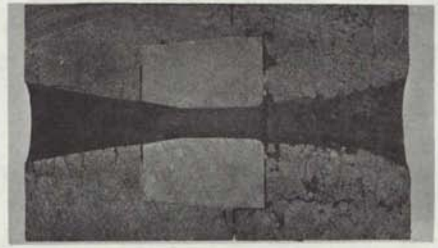
Figure 6. TU-379 Exit Cone Erosion and Char Profile

TABLE 10
SUMMARY OF INFORMATION ON CANDIDATE MATERIALS

Material		Vendor	Material Description: Reinforcement	Filler	Resin	Specific Gravity	TU-379 Erosion and Char Data: Inlet Erosion Station	Mil/Sec	Inlet Char Station	Mil/Sec	Exit Erosion Station	Mil/Sec	Exit Char Station	Mil/Sec	Cost/lb ($)	Comments
SP-8027	Carbon Reinforced	Armour	Pluton B-1	Graphite	EC-201 Phenolic	1.4	1	3.1	5	14.6	1	0	7	11.9	13.00	
							8	4.4	15	17.2	7	0				
							9	4.9			14	0				
							Max	5.6			Max	0				
FM-5072 LD	Carbon Reinforced	US Polymeric	VCK Carbon	Microballoons	91 LD Phenolic	1.2	1	3.0	5	18.9	1	0	7	14.2	23.25	
							8	8.3	15	21.2	7	0				
							9	6.3			14	0				
							Max	9.1			Max	0				
4C 1896	Carbon Reinforced	Coast	GS-CC2 Carbon	Graphite	Polyphenylene	1.3	1	1.3	5	20.1	1	0	7	17.7	20.60	
							8	3.0	15	21.7	7	0				
							9	3.6			14	0				
							Max	4.5			Max	0				
MXC-198	Carbon Reinforced	Fiberite	CCA-1 Carbon	--	HT-105 Epoxy Novalac	1.1	1	7.1	5	70.5	1	2.5	7	28.1	21.50	
							8	22.1	15	80.6	7	6.4				
							9	19.8			14	0				
							Max	27.9			Max	8.2				
WB-8251	Avceram Reinforced	Corde	Avceram C/S	Graphite	WB-2233 Phenolic	1.5	1	3.2	5	15.0	1	0	7	14.0	22.97	
							8	7.0	15	16.8	7	0				
							9	7.7			14	0				
							Max	8.3			Max	0				
4C 2530	Avceram Reinforced	Coast	Avceram C/S	None	EC-201 Phenolic	1.4	1	4.4	5	18.9	1	0	7	10.8	13.25	
							8	9.3	15	20.7	7	0.2				
							9	9.1			14	0				
							Max	11.7			Max	0.6				
MXCS-198	Avceram Reinforced	Fiberite	Avceram C/S	--	HT-505 Epoxy Novalac											Material has not been evaluated specifically.
4S 5186	Silica Reinforced	Coast	C-100-96 Silica	Silica	Polyphenylene	1.7	1	5.7	5	18.3	1	0	7	12.8	5.35	
							8	11.4	15	17.4	7	0				
							9	13.9			14	0				
							Max	14.1			Max	0				
SP-8050-96	Silica Reinforced	Armour	C-100-96 Silica	Silica Phenolic	EC-201 Phenolic	1.6	1	4.7	5	20.6	1	0	7	13.1	4.90	
							8	13.0	15	18.3	7	0				
							9	13.2			14	0				
							Max	13.7			Max	0				
MXS-313	Silica Reinforced	Fiberite	Silica Fibers		MIL-R-9299 Phenolic	0.8									4.75	Erosion and char surpassed measurable stage.
4065	Silica Reinforced	Narmco	C-100-28 Silica	Phenolic Microballoons	Phenolic Nitrile	1.0	1	5.8	5	22.2	1	0.4	7	14.4	18.98	
							8	19.3	15	26.9	7	5.1				
							9	27.6			14	0.6				
							Max	27.6			Max	6.9				
MXS-198	Silica Reinforced	Fiberite	C-100-48 Silica	--	HT-105 Epoxy Novalac	1.5	1	1	5	45.2	1	1.5	7	13.8	6.10	
							8	22.7	15	52.3	7	2.9				
							9	25.5			14	0				
							Max	33.7			Max	4.0				
MXA-313	Asbestos Reinforced	Fiberite	Asbestos		MIL-R-9299 Phenolic	1.6	1	7.0	5	16.6	1	0.9	7	18.9	2.25	
							8	15.0	15	20.5	7	4.4				
							9	18.4			14	0.4				
							Max	18.4			Max	5.1				
4A 5385	Asbestos Reinforced	Coast	Asbestos	Silica Microballoons	Polyphenylene	1.4	1	5.9	5	16.1	1	1.5	7	10.7	3.50	
							8	12.2	15	21.6	7	5.1				
							9	16.2			14	0.4				
							Max	19.2			Max	5.3				
33-RPD	Asbestos Reinforced	Raybestos-Manhattan	Asbestos	Cork	Phenolic	1.8	1	6.7	5	14.4	1	1.1	7	7.4	4.23	
							8	13.1	15	15.4	7	2.8				
							9	12.4			14	0				
							Max	13.1			Max	3.7				
WB-7605	Paper Reinforced	Corde	Asbestos	Phenolic Microballoons	Phenolic	--										Material delaminates severely.
SMS-21	Paper Reinforced	Thiokol	Paper	None	Phenolic	1.3	1	4.9	5	11.7	1	0.6	7	12.4	1.20	
							8	5.5	15	14.6	7	7.7				
							9	6.1			14	2.3				
							Max	9.6			Max	9.9				
LCCM-2810		Thiokol	None	Graphite	SC-1008 Phenolic	1.8	1	0	5	26.9	1	0	7	20.2	0.75	
							8	0	15	30.3	7	0				
							8	0			14	0				
							Max	0			Max	0				
LCCM-4120	Low Cost Carbonaceous	Thiokol	None	Graphite	Durez 10694 Phenolic	1.5	1	2.9			1	0.2			0.75	Char line was indistinguishable from virgin material and could not be measured.
							8	5.6			7	0				
							9	6.6			14	0				
							Max	10.4			Max	0.2				
LCCM-4113	Low Cost Carbonaceous	Thiokol	--	Graphite	Phenolic Durez 10694 Hitco 158 Nitrile	1.8										Erosion and char surpassed measurable stage.
LCCM-Reinforced		Thiokol														Material not sufficiently developed for evaluation.

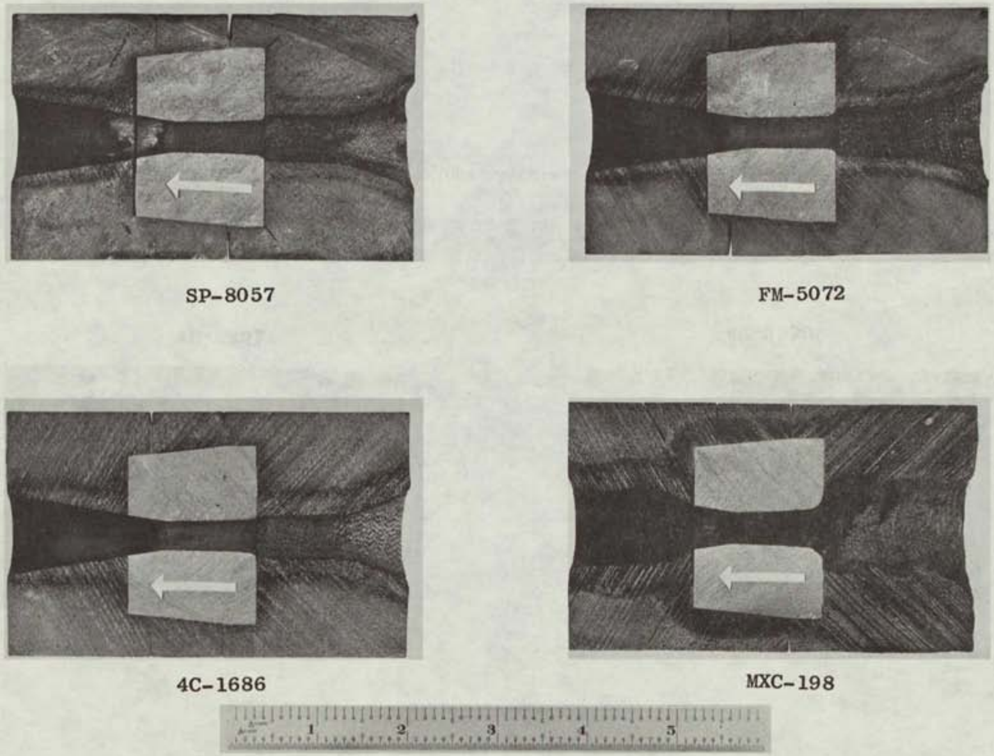


LCCM-2610



LCCM-4120

Figure 7. Fired TU-379 Nozzle Sections, Low Cost Carbonaceous Materials



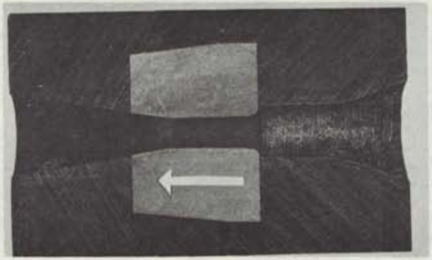
SP-8057

FM-5072

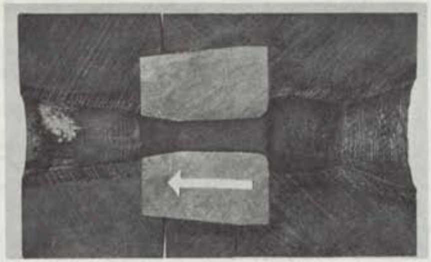
4C-1686

MXC-198

Figure 8. Fired TU-379 Nozzle Sections, Carbon Cloth Reinforced Materials

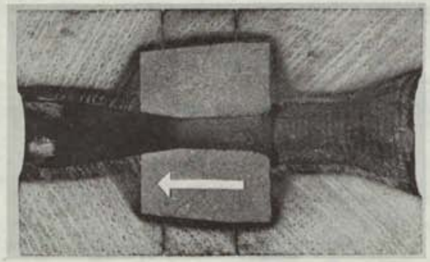


WB-8251

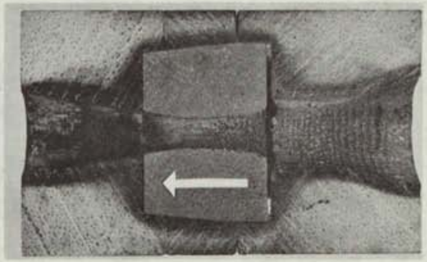


4C-2530

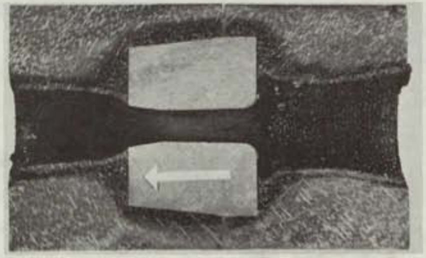
Figure 9. Fired TU-379 Nozzle Sections, Avceram C/S Cloth Reinforced Materials



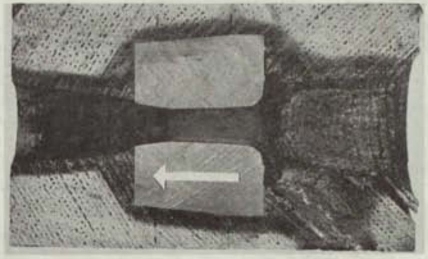
4S-5186



SP-8030-96

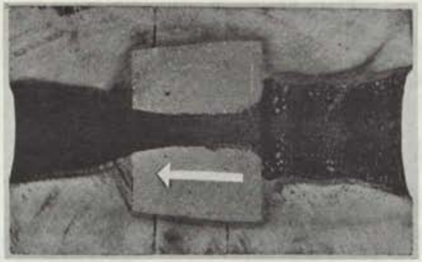


4065

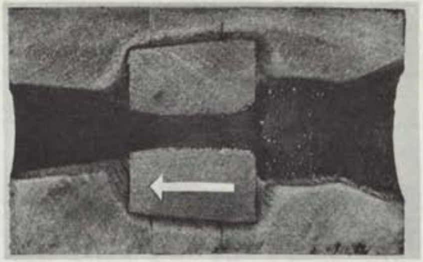


MXS-198

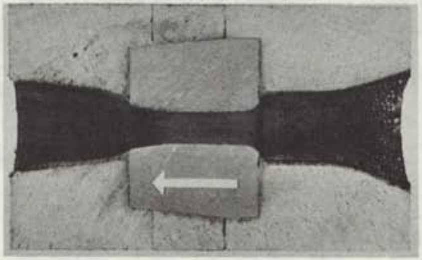
Figure 10. Fired TU-379 Nozzle Sections Silica Cloth Reinforced Materials



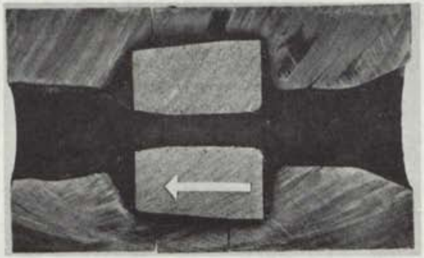
MXA-313



4A-6385



23-RPD



SMS-21

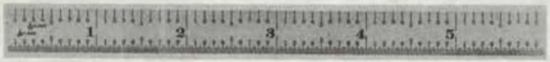


Figure 11. Fired TU-379 Nozzle Sections, Asbestos and Paper Reinforced Materials

TABLE 11

MATERIALS RECOMMENDED FOR FURTHER EVALUATION

Material	Vendor	General Description	Cost $/lb	Remarks
LCCM-2610	Thiokol	Graphite particle - phenolic molding compound	0.75	Excellent erosion resistance, very low cost, demonstrated successfully in char motor nozzles (D_T = 3.8 in.) and Stage II Minuteman nozzle (D_T = 8.5 in.).
LCCM-4120	Thiokol	Graphite particle - phenolic castable compound	0.75	Good erosion resistance as demonstrated in the exit cones of char nozzles (D_T = 3.8 in.) and Stage II Minuteman nozzle (D_T = 8.5 in.). Material can be cast in place and cured at low pressure (15 psi), and is very low in cost.
SP-8057	Armour	Pluton H-1 fabric in EC-201 phenolic resin	15.00	Good erosion resistance that is comparable to the best carbon fabric - phenolic materials. Material has a 50 percent resin content; and therefore, a relatively low cost for this class of material.
4C1686	Coast	GS-CC2 carbon fabric in polyphenylene resin	20.60	Good erosion resistance, and reasonable cost for this type of material.
WB-8251	Cordo	Avceram C/S in WB-2233 phenolic resin	12.97	Erosion resistance is comparable to carbon - phenolic materials. Has lower price than carbon-phenolic materials. Has lower thermal conductivity than carbon - phenolic materials.
MXCS-198	Fiberite	Avceram C/S in epoxy - novolac resin		This material has not been tested but is recommended because of its potential advantages. Avceram reinforcement has shown excellent results in both this program and the Nomad program. Avceram performance is similar to that of carbon cloth but is lower in cost. Epoxy novolac resins have performed well in the Nomad program. They have the advantage of being cured at low pressure; therefore, Thiokol recommends that lower cost Avceram be combined with low pressure curing epoxy novolac resin.
SP-8030-96 or SP-8030-48	Armour	C-100-96 Silica or C-100-48 Silica	4.90	Good performing low cost silica - phenolic. Can be wrapped successfully in double thickness, reducing fabrication costs.
MXS-198	Fiberité	C-100-96 Silica	6.10	Adequate erosion resistance. Can be fabricated at low pressures, reducing facility requirements and fabrication costs.
23 RPD	Raybestos-Manhattan	Asbestos mat with cork filler and phenolic resin	4.25	Excellent backup material. Has good char properties. Good erosion resistance for asbestos - phenolic.
4065	Narmco	C-100-20 Silica fabric, phenolic microballoon filled, phenolic modified nitrile	18.08	Low density material. Would make a good backup insulation material because of its low density.

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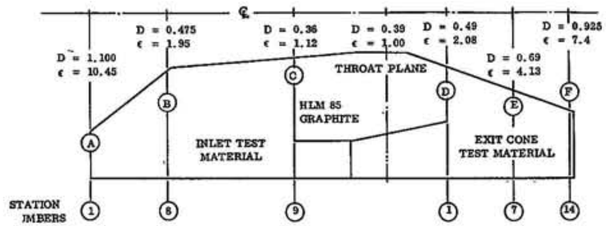
TABLE 12

TU-379 MOTOR MATERIAL PERFORMANCE



Nozzle Location with Material Erosion and Char Rates (mil/sec)

Material		Station 1 (A) UC	Station 1 (A) C	Station 8 (B) UC	Station 8 (B) C	Station 9 (C) UC	Station 9 (C) C	Station 1 (D) UC	Station 1 (D) C	Station 7 (E) UC	Station 7 (E) C	Station 14 (F) UC	Station 14 (F) C
	Erosion (1)	0.0	0.0	0.0	0.0	0 0	0.0	0 0	0.0	0.0	0.0	0.0	0.0
1. LCCM T2610	Char	18.6	18.9	31.7	32.2	(5)	(5)	(5)	(5)	19.0	19.3	12.0	12.1
	Erosion (1)	2.9	3.2	5.6	6 2	8.8	9.7	0.2	0.2	0.0	0.0	0.0	0.0
2 LCCM T4120	Char	N/A	N/A	N/A	N/A	(5)	(5)	(5)	(5)	N/A	N/A	N/A	N/A
	Erosion (1)	1.3	1.3	3.0	3.0	3.6	3.6	0.0	0 0	0.0	0.0	0.0	0.0
3. 4C-1686	Char	20 6	20.6	22.6	22 6	(5)	(5)	(5)	(5)	16.8	16.8	6.4	6.4
	Erosion (1)	3.1	2 8	4 4	4.1	4.9	4.6	0.0	0.0	0.0	0.0	0.0	0.0
4. SP-8057	Char	14.7	14.3	15.9	15.4	(5)	(5)	(5)	(5)	10.6	10.5	5.7	5.6
	Erosion (1)	3 2	3.3	7.0	7.2	7.7	7.9	0.0	0.0	0.0	0.0	0 0	0.0
5. WB-8251	Char	14.1	14.4	17.1	17.4	(5)	(5)	(5)	(5)	13.0	13.2	6 3	6.4
	Erosion (1)	MATERIAL NOT EVALUATED											
6. MXCS-198	Char												
	Erosion (1)	4.7	4.8	13 0	13.3	13.2	13 5	0.0	0.0	0.0	0.0	0.0	0 0
7. SP-803-96	Char	13.7	14.0	21.9	22.3	(5)	(5)	(5)	(5)	12.1	12.1	7.0	7.0
	Erosion (1)	N/A	N/A	22.7	22.9	25.5	25.8	1.5	1.5	2.9	2.9	0.0	0.0
8. MXS-198	Char	N/A	N/A	54.4 (7)	55.1 (7)	(5)	(5)	(5)	(5)	13.3 (7)	13.5 (7)	6.6 (7)	6.7 (7)
	Erosion (1)	6 7	6.6	13.1	12.8	12.4	12.2	1.1	1.1	2.8	2.7	0.0	0.0
9. 23RPD	Char	12.7	12 5	16.6	16.4	(5)	(5)	(5)	(5)	6.9	6.8	3.3	3.2
	Erosion (1)	6.9	6 8	5.5	5 4	8.1	7.9	0.6	0.6	7.7	7.5	2.3	2.3
10. SMS-21	Char	12.6	12.4	12.8	12.7	(5)	(5)	(5)	(5)	11.5	11.6	5.1	5.0

Motor Parameters / Material Erosion Factors

Material	Avg Web Pressure (psi) (3)	Throat Diameter (in.)	Propellant Grain Design	Propellant Formulation	Nozzle Type	Nozzle Shape	Web Burn Time (sec) (3)	Erosion Press. Corr Factor to Avg Press. of all the Motors and all the Materials	Erosion Dia Corr Factor	Erosion Nozzle Contour & Shape Corr Factor	Erosion Propellant Grain Corr Factor	Erosion Propellant Formulation Corr Factor	Erosion Nozzle Type Corr Factor	Material Char Corr Factor: Char Time Corr Factor to Avg Time of all the Motors and all of the Materials
1. LCCM T2610	428	0.34	End Burner	Scrap TP-H1011	Fixed External	1) 2 deg Inlet 2) 9 1/2 Exit	15.46	0.99	1.00	1.00	1.00	1 00	1.00	0.98
2 LCCM T4120	375	Assume Same for All Nozzles	Assume Same for All Nozzles	Assume Same for All Nozzles	Assume Same for All Nozzles	Assume Same for All Nozzles	15.04	1.10	Assume Constant	Assume Constant	Assume Constant	Assume Constant	Assume Constant	0.98
3. 4C-1686	418						14.92	1.01						1.00
4. SP-8057	460						14.29	0.93						1.03
5. WB-8251	407						15.37	1.03						0.98
6. MXCS-198	N/A						N/A	N/A						N/A
7. SP-803-96	413						15.51	1.02						0.97
8. MXS-198	416						15.62	1.01						0.97
9. 23RPD	434						14.76	0.98						1.01
10. SMS-21	436						15.04	0.98						0.98
	422 Avg Web Pressure						14 91 Avg Web Time							

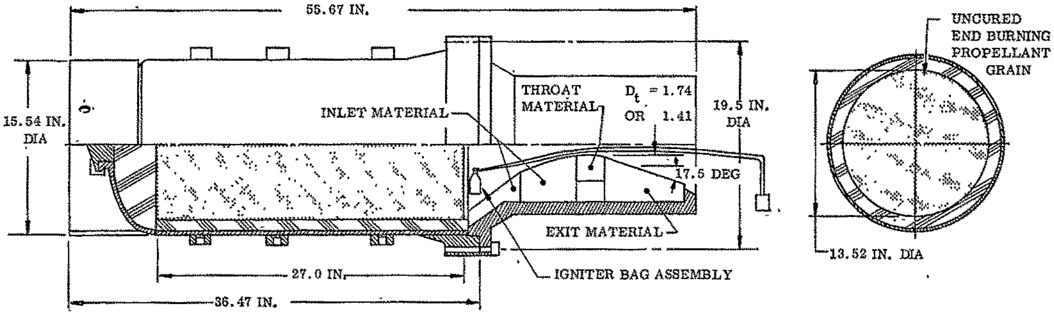
$$\text{Erosion Press Factor} = \frac{\left(\frac{422\ 44}{1,000}\right)^{1/1.25}}{\left(\frac{X}{1,000}\right)^{1/1.25}} = \frac{0.502}{(\quad)}$$

$$\text{Char Time Factor} = \frac{(14.91)^{1/1.47}}{(\quad)^{1/1.47}} = \frac{6.29}{(\quad)}$$

NOTES.
1. Erosion and char rates corrected for pressure and time.
2. Erosion and char as pictured: EROSION, CHAR
3. Average of three nozzle tests for each material.
4. Erosion and char measured ⊥ to ℄.
5. Values not realistic due to graphite throat ring
6. Definitions: UC = Uncorrected; C = Corrected; N/A = Not Available
7. Poor Fabrication Processing of Material

FOLDOUT FRAME

FOLDOUT FRAME



DESIGN I	DESIGN II
P_{MAX} = 500 PSIA	P_{MAX} = 1,000 PSIA
P_{MIN} = 315 PSIA	P_{MIN} = 100 PSIA
P_{AVG} = 400 PSIA	P_{AVG} = 400 PSIA
T_b = 30 SEC	T_b = 35 SEC
D_T = 1.74 IN.	D_T = 1.41 IN.

24535-33

Figure 12. TU-622 Materials Evaluation Motor

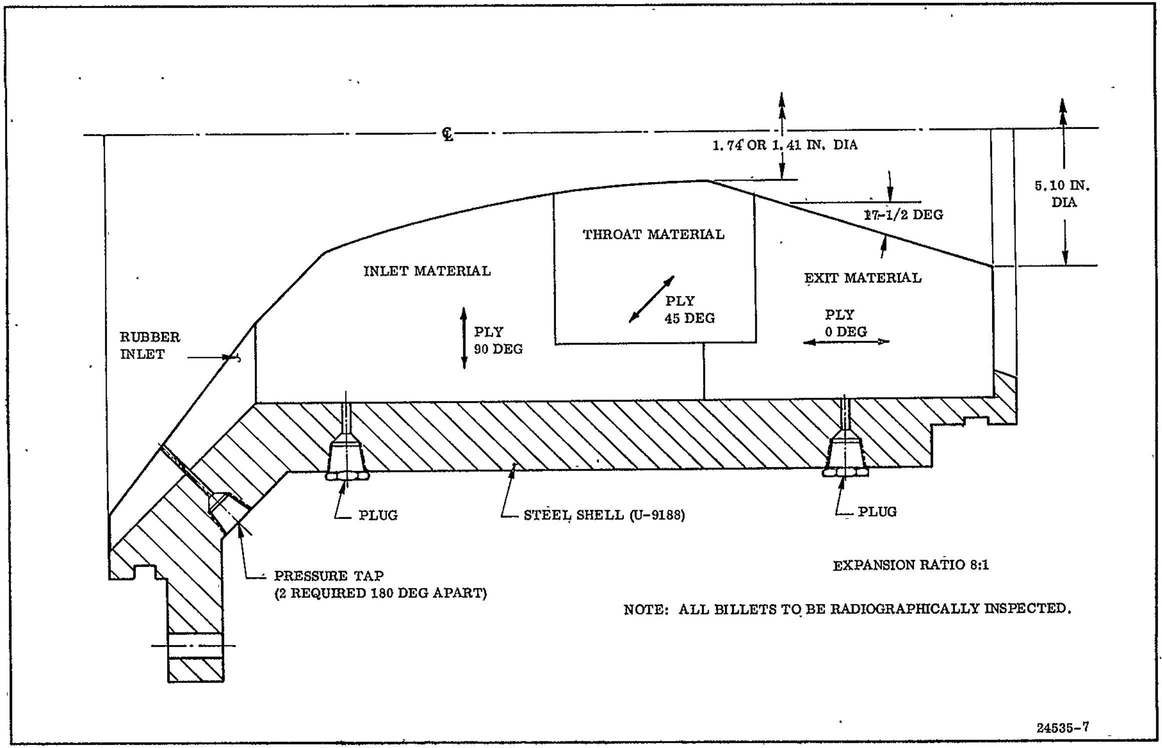


Figure 13. TU-622 Materials Evaluation Nozzle

TABLE 13

TU-622 NOZZLE COMPONENT CURE SUMMARY

Material	Component	Cure
1. 4C-1686	Inlet	Apply 225 psi. Cure 2.5 hr at 180°F, 2.5 hr at 210°F, 2.5 hr at 240°F, 2.5 hr at 270°F, 2.5 hr at 300°F, and 6 hr at 350°F. Cool under pressure to 150°F.
	Throat	Same as for inlet.
	Exit cone	Stage 1 hr at 180°F under vacuum. Apply 225 psi. Cure 2.5 hr at 200°F, 2.25 hr at 240°F, 2.25 hr at 270°F, 2 hr at 300°F, 2.5 hr at 350°F. Cool under pressure and vacuum to 160°F.
2. WB-8251	Inlet	Debulk 2 hr at 170°F and 225 psi. Cool to 100°F under pressure. Additional plies added. Apply 225 psi. Cure 4 hr at 170°F, 4 hr at 200°F, 4 hr at 230°F, 3 hr at 265°F, and 6 hr at 300°F. Cool under pressure to 160°F.
	Throat	Same as for inlet.
	Exit cone	Apply vacuum and 225 psi. Cure 1.5 hr at 180°F, 1.5 hr at 200°F, 3 hr at 225°F, 3 hr at 250°F, and 6 hr at 310°F. Cool under vacuum and pressure to 140°F.
3. SMS-21	Inlet	Apply 225 psi. Cure 1 hr at 180°F, 2 hr at 250°F, 6 hr at 320°F. Cool under pressure to 160°F.
	Throat	Same as for inlet.
	Exit cone	Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 250°F, and 6 hr at 310°F. Cool under pressure to 160°F.
4. SP-8030-96	Inlet	Apply 225 psi. Cure 2.5 hr at 200°F, 2.5 hr at 250°F, and 6 hr at 310°F. Cool under pressure to 160°F.
	Throat	Same as for inlet.
	Exit cone	Apply vacuum and 225 psi. Cure 1.5 hr at 180°F, 1.5 hr at 200°F, 3 hr at 225°F, 3 hr at 250°F, and 6 hr at 310°F. Cool under vacuum and pressure to 140°F.
5. SP-8057	Inlet	Apply 225 psi. Cure 1 hr at 180°F, 1 hr at 210°F, 2 hr at 240°F, 2 hr at 275°F, and 5 hr at 310°F. Cool under pressure to 150°F.
	Throat	Same as for inlet
	Exit cone	Apply vacuum and stage 0.5 hr at 180°F. Apply 225 psi. Cure 2 hr at 180°F, 2 hr at 210°F, 2 hr at 240°F, 2 hr at 275°F, and 4.5 hr at 310°F. Cool under vacuum and pressure to 150°F.
6. LCCM-2610	Inlet	Debulk at 170°F and 1,000 psi as required. Cure 8 hr at 325°F and 1,000 psi. Cool under pressure to 170°F.
	Throat	Cure 6 hr at 300°F and 1,000 psi.
	Exit cone	Same as for throat.

TABLE 13. –Continued

TU-622 NOZZLE COMPONENT CURE SUMMARY

	Material	Component	Cure
7.	LCCM-4120	Inlet	Apply vacuum. Cure 8 hr at 310°F.
		Throat	Same as for inlet.
		Exit cone	Same as for inlet.
8.	23-RPD	Inlet	Debulk extensively at 180°F and 150 psi. Apply 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, and 6 hr at 310°F. Cool under pressure to 150°F.
		Throat	Same as for inlet.
		Exit cone	Stage under vacuum 2 hr at 180°F. Apply 225 psi. Cure 2 hr at 180°F, 2 hr at 250°F, 3 hr at 275°F, and 6 hr at 300°F. Cool under vacuum and pressure to 140°F.
9.	MXS-198	Inlet	Debulk 2 hr at 180°F and 140 psi. Remove pressure. Apply vacuum. Cure 2 hr at 175°F, 4 hr at 210°F, 4 hr at 240°F, and 9 hr at 325°F. Cool under vacuum to 150°F.
		Throat	Same as for inlet.
		Exit cone	Apply vacuum. Cure 3 hr at 180°F, 4 hr at 210°F, 4 hr at 240°F, and 9 hr at 325°F. Cool under vacuum to 180°F.
10.	MXCS-198	Inlet	Debulk 2 hr at 180°F and 140 psi. Remove pressure. Apply vacuum bag. Apply vacuum. Cure 2 hr at 180°F, 4 hr at 210°F, 4 hr at 240°F, and 9 hr at 325°F. Cool under vacuum to 160°F.
		Throat	Same as for inlet.
		Exit cone	Apply vacuum. Cure 3 hr at 180°F, 4 hr at 210°F, 4 hr at 240°F, and 9 hr at 325°F. Cool under vacuum to 180°F.

TABLE 14

FABRICATION PROBLEM SUMMARY
TU-622 NOZZLE ASSEMBLIES

Nozzle and Material	Component	Problem	Solution
1. SK-41798-01 (LCCM-2610)	Inlet	None	
	Throat	None	
	Exit cone	None	
2. SK-41798-02 (4C-1686)	Inlet	None	
	Throat	None	
	Exit cone	None	
3. SK-41798-03 (WB-8251)	Inlet	Numerous delaminations over half the length of the billet.	Machined off delaminated area. Added new plies and cured to a longer cure cycle.
	Throat	Several large delaminations which could not be machined out.	Scrapped part. Remade with fresh material and longer cure cycle.
	Exit cone	Severe cracks and delaminations throughout.	Scrapped part. Insufficient time left to reorder material. Substituted segmented LCCM-2626 exit cone.
4. SK-41798-04 (SP-8057)	Inlet	Billet fabricated too short. No additional material on hand.	Added plies of SP-8030-96 to one end and cured. Machined so that SP-8030-96 was located at extreme forward end.
	Throat	Oriented 45 deg upstream.	Used as is.
	Exit cone	None	
5. SK-41798-05 (MXCS-198)	Inlet	None	
	Throat	Throat diameter machined too big.	Redesigned to a different contour.
	Exit cone	Extensive cracks and delaminations.	Scrapped part. Insufficient time left to reorder material. Substituted segmented LCCM-2610 exit cone.
6. SK-41798-06 (LCCM-4120)	Inlet	None	
	Throat	None	
	Exit cone	None	
7. SK-41798-07 (SP-8030-96)	Inlet	None	
	Throat	None	
	Exit cone	None	
8. SK-41798-08 (MXS-198)	Inlet	None	
	Throat	Machining to throat diameter left resin starved areas. Continued machining until such areas were eliminated, resulting in too large a throat diameter.	Machined and installed throat insert (2 pieces) of standard silica phenolic material (MX-2600).
	Exit cone	As molded part had several large resin starved areas, which delaminated extensively during machining.	Scrapped part. Insufficient time left to reorder material. Substituted LCCM-2626 exit cone.

TABLE 14. -Continued

FABRICATION PROBLEM SUMMARY
TU-622 NOZZLE ASSEMBLIES

	Nozzle and Material			Solution
9.	SK-41798-09 (23-RPD)		None	
			None	
			Shrank more during cure than expected, resulting in too small an OD.	Added graphite sleeve.
10.	SK-41798-10 (SMS-21)	Inlet	None	
		Throat	None	
		Exit cone	None	

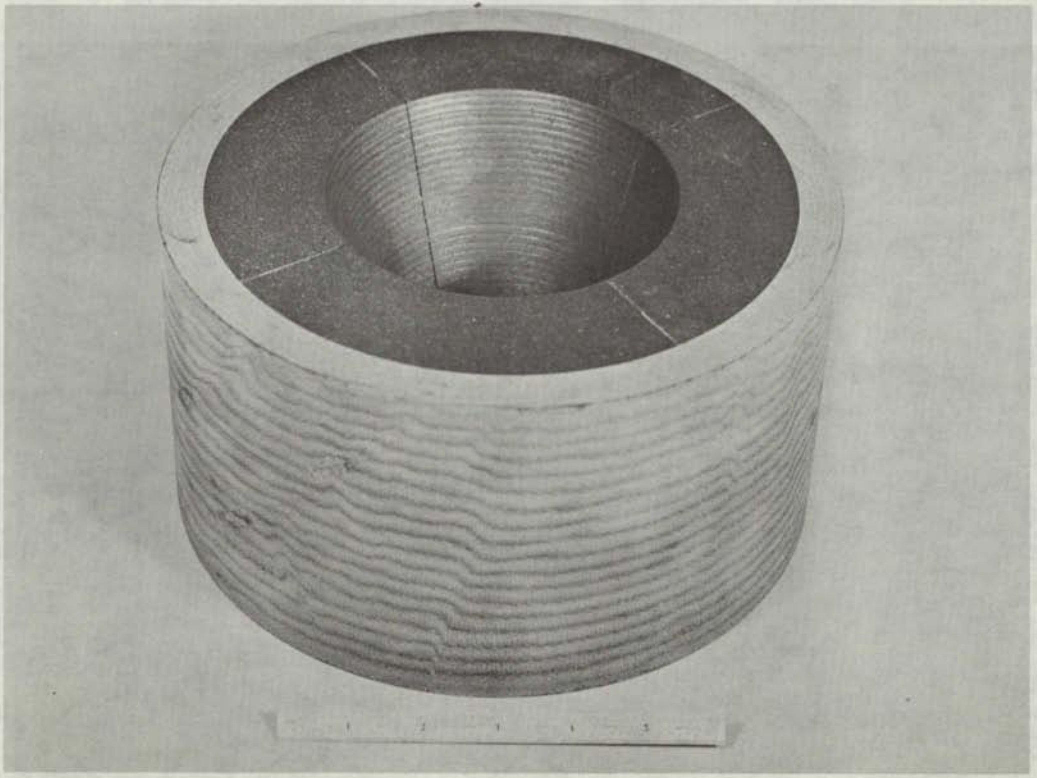


Figure 14. TU-622 Segmented LCCM-2626 Exit Cone (View A)

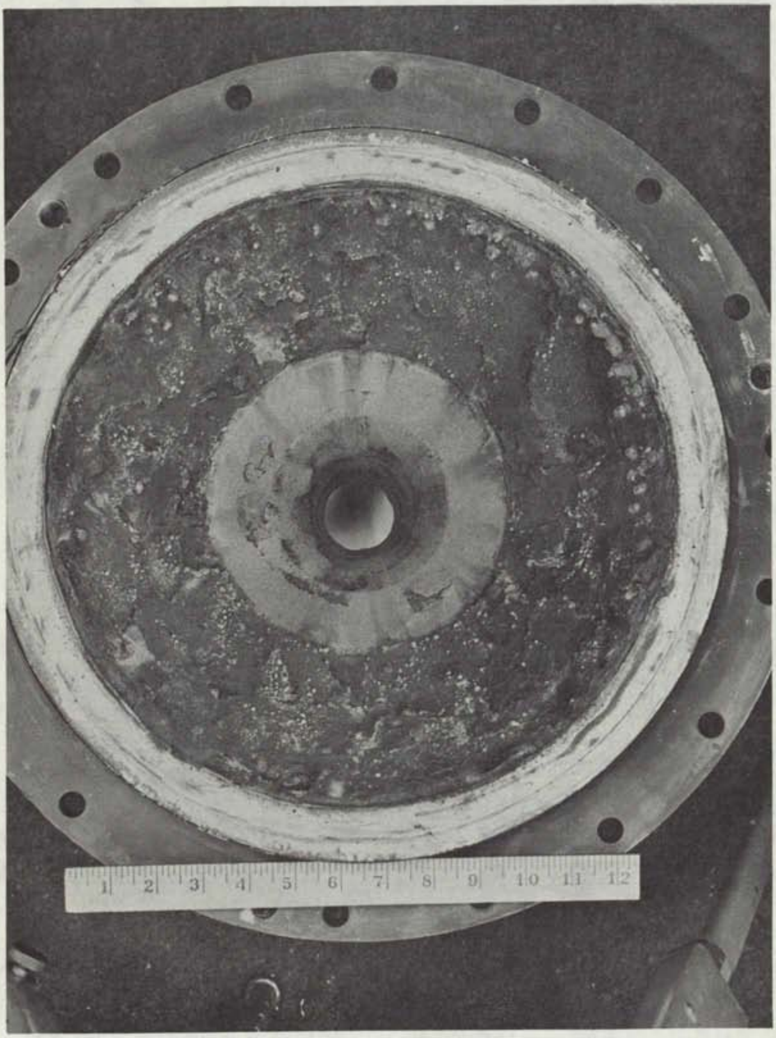


Figure 15. Forward End TU-622 Test Nozzle, LCCM-2610 (Graphite Phenolic)

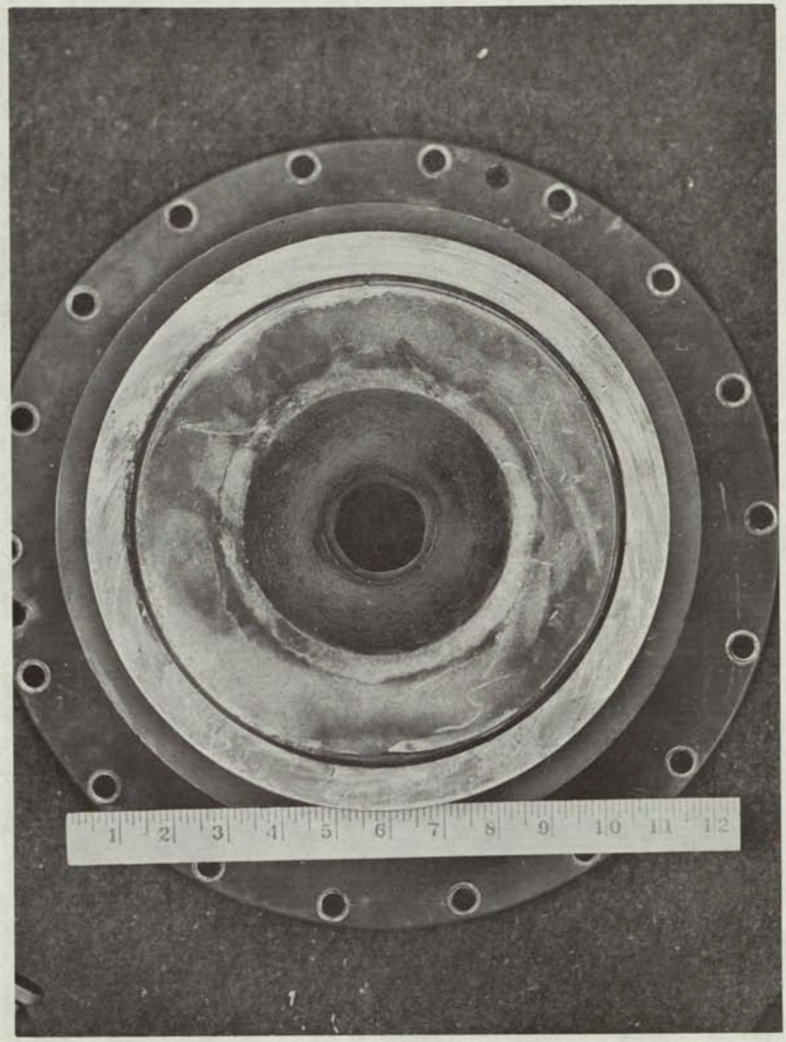


Figure 16. Aft End TU-622 Test Nozzle, LCCM-2610 (Graphite Phenolic)

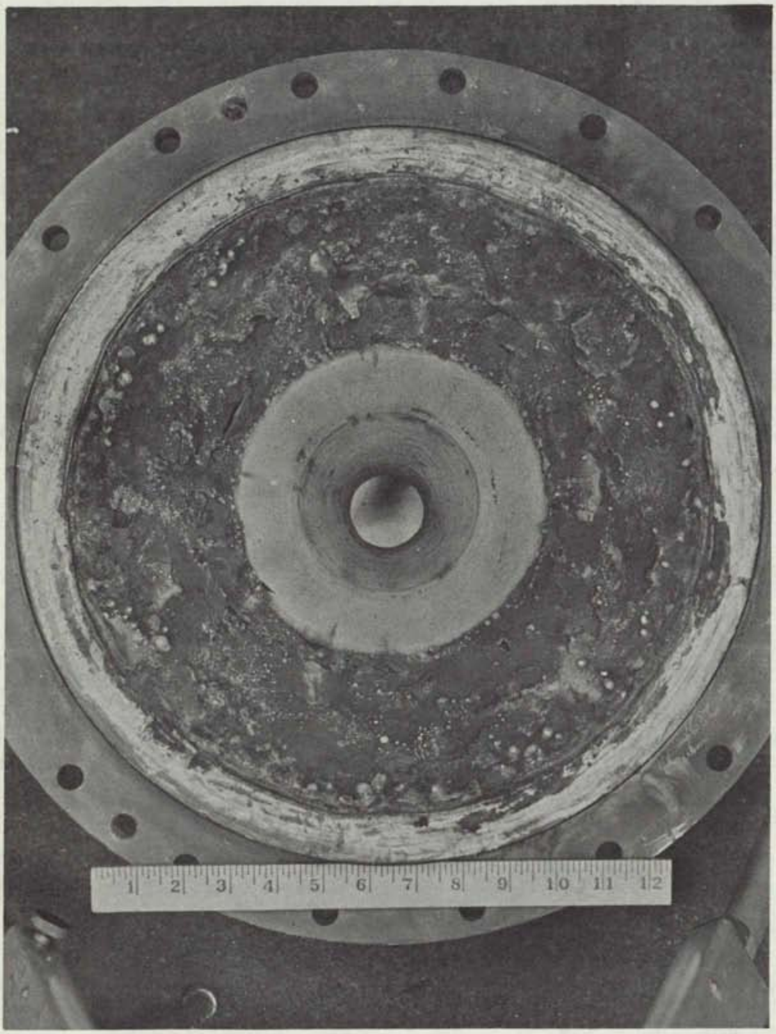


Figure 17. Forward End TU-622 Test Nozzle, 4C-1686 (Carbon Cloth Polyphenylene)

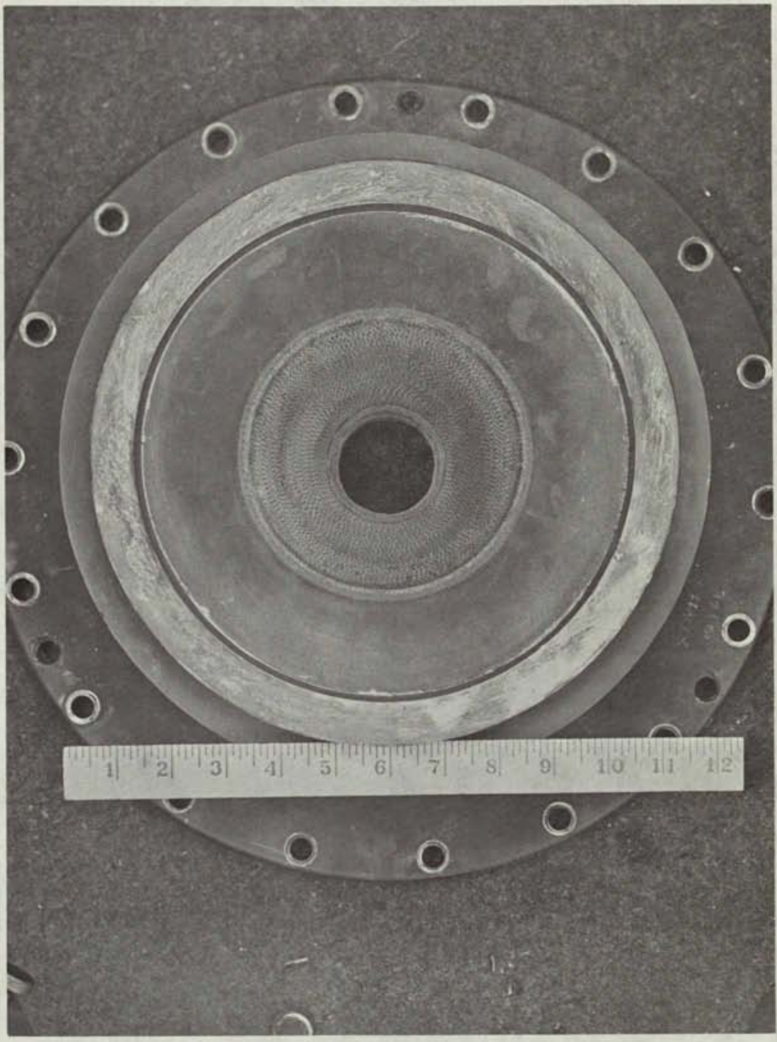


Figure 18. Aft End TU-622 Test Nozzle, 4C-1686 (Carbon Cloth Polyphenylene)

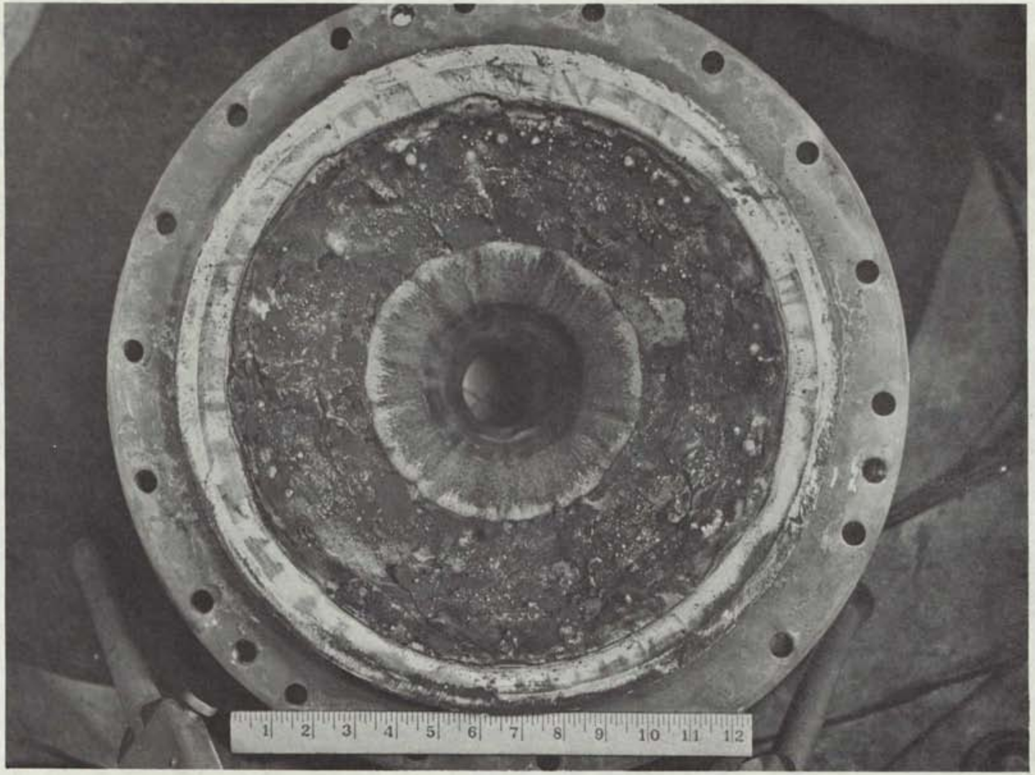


Figure 19. Forward End TU-622 Test Nozzle, WB-8251 (Avceram C/S-Phenolic) Inlet and Throat, LCCM-2610 Dry (Graphite-Phenolic) Segmented Exit Cone

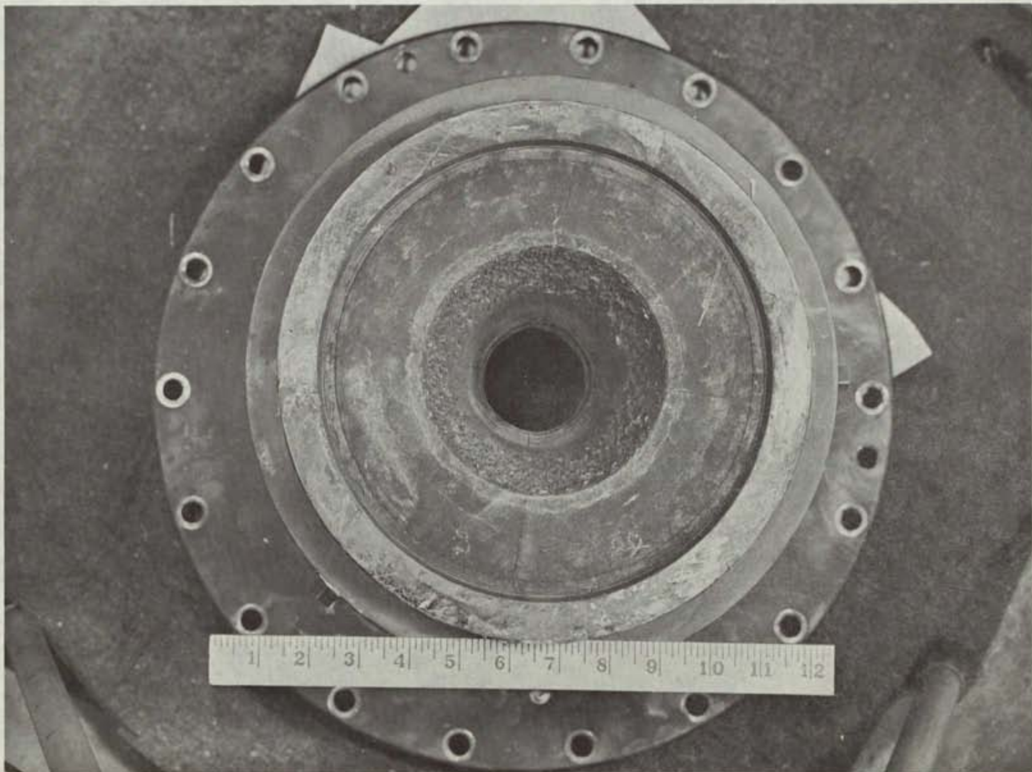


Figure 20. Aft End TU-622 Test Nozzle, WB-8251 (Avceram C/S-Phenolic) Inlet and Throat, LCCM-2610 Dry (Graphite-Phenolic) Segmented Exit Cone

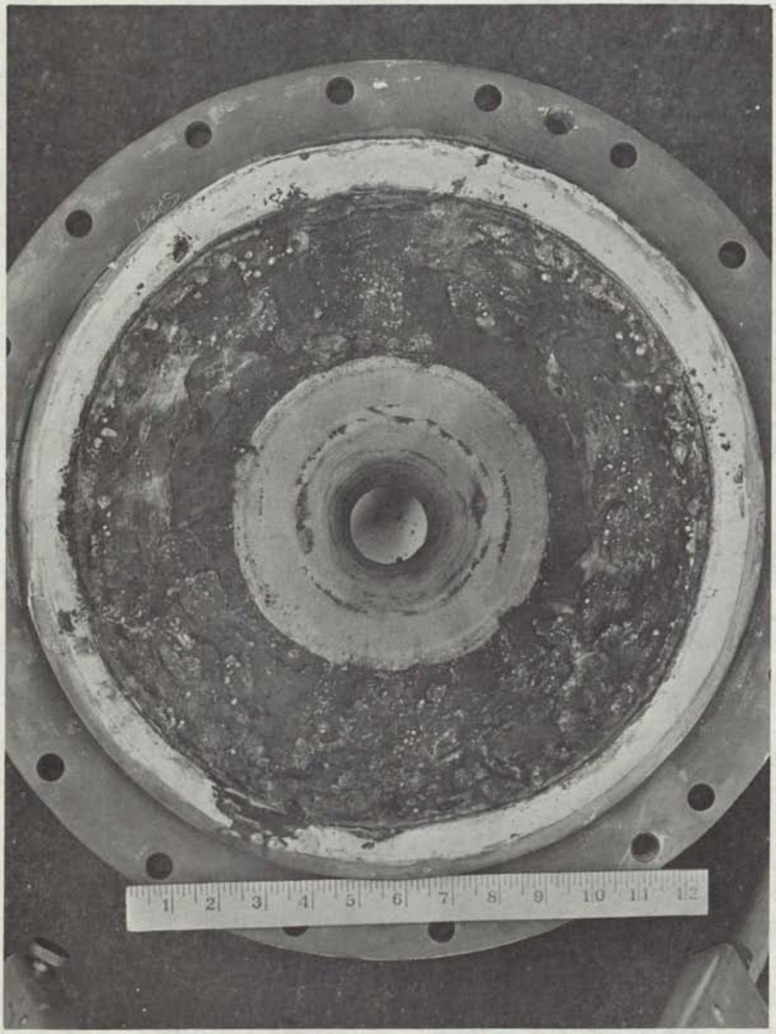


Figure 21. Forward End TU-622 Test Nozzle, SP-8057 (Pluton H-1 Phenolic)

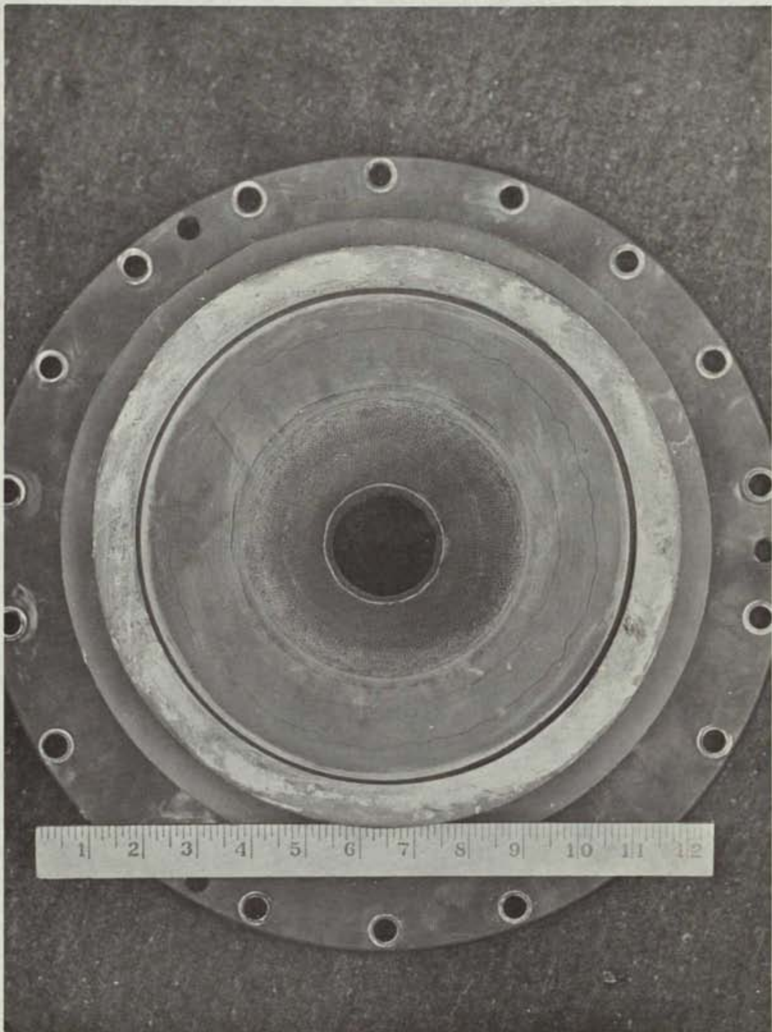


Figure 22. Aft End TU-622 Test Nozzle, SP-8057 (Pluton H-1 Phenolic)

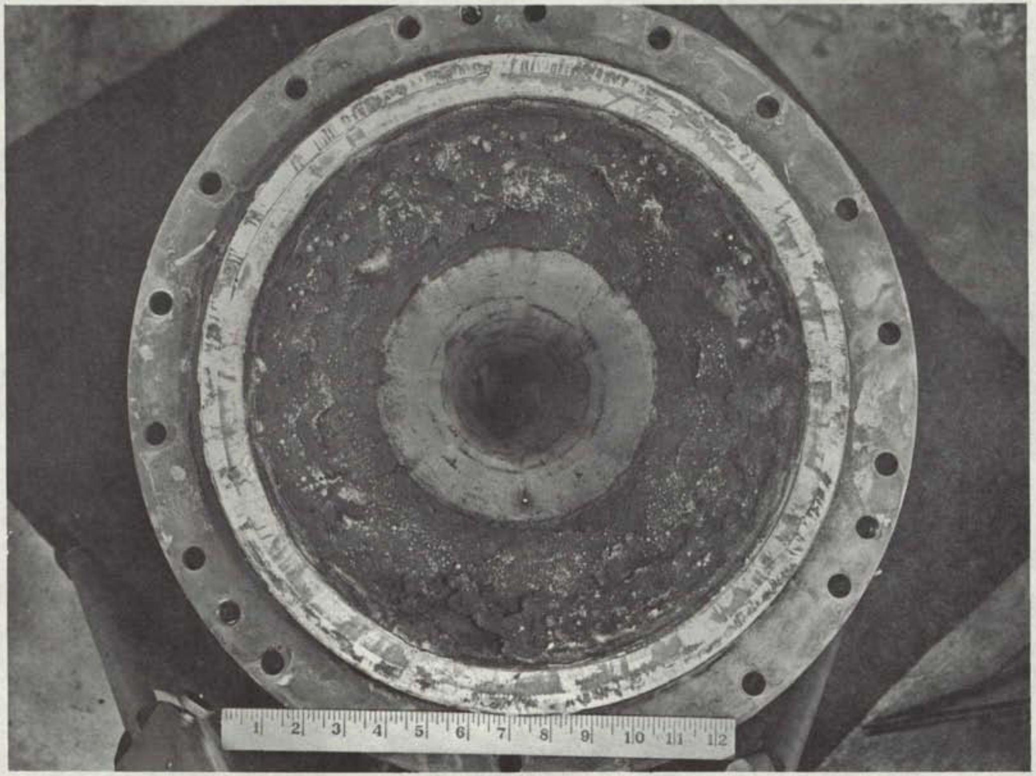


Figure 23. Forward End TU-622 Test Nozzle, MXCS-198 (Avceram C/S-Epoxy Novolac Inlet and Throat, LCCM-2610 (Graphite-Phenolic) Segmented Exit Cone

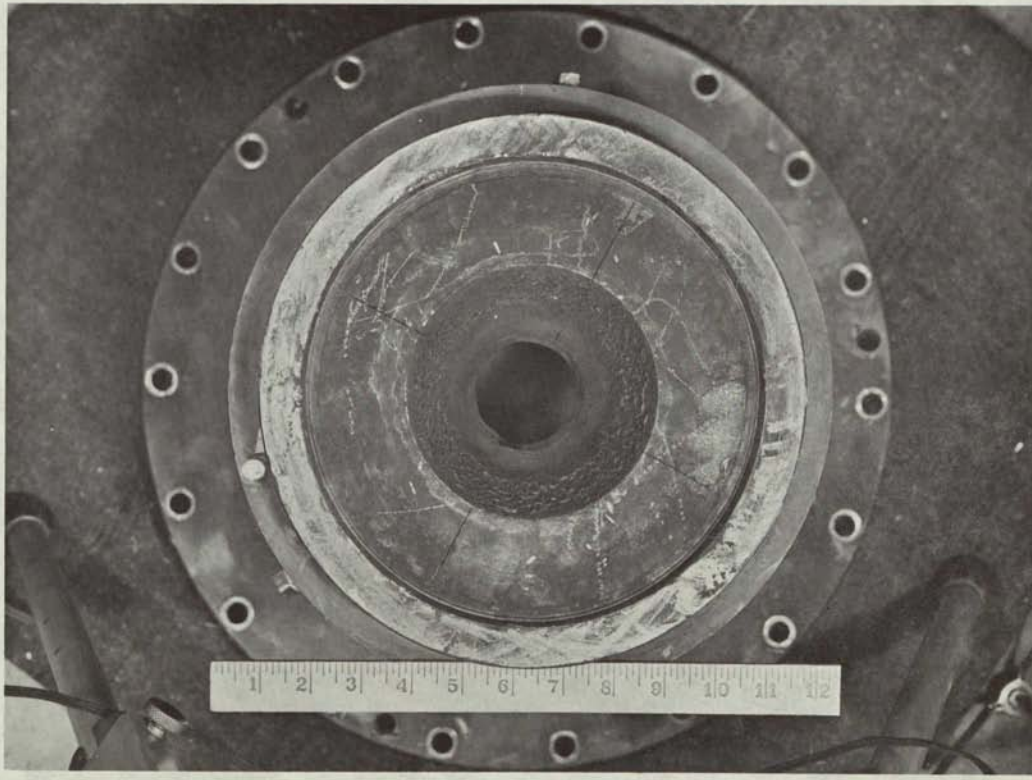


Figure 24. Aft End TU-622 Test Nozzle, MXCS-198 (Avceram C/S Epoxy Novolac) Inlet and Throat, LCCM-2610 (Graphite-Phenolic) Segmented Exit Cone

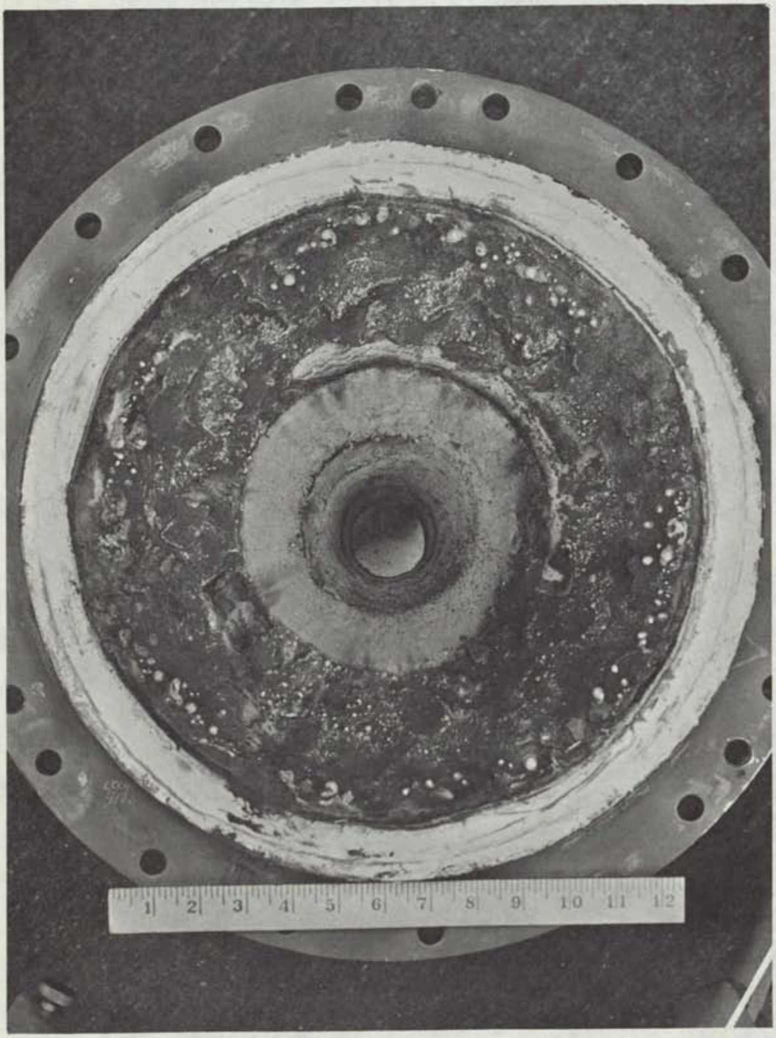


Figure 25. Forward End TU-622 Test Nozzle
LCCM-4120 (Graphite Phenolic)

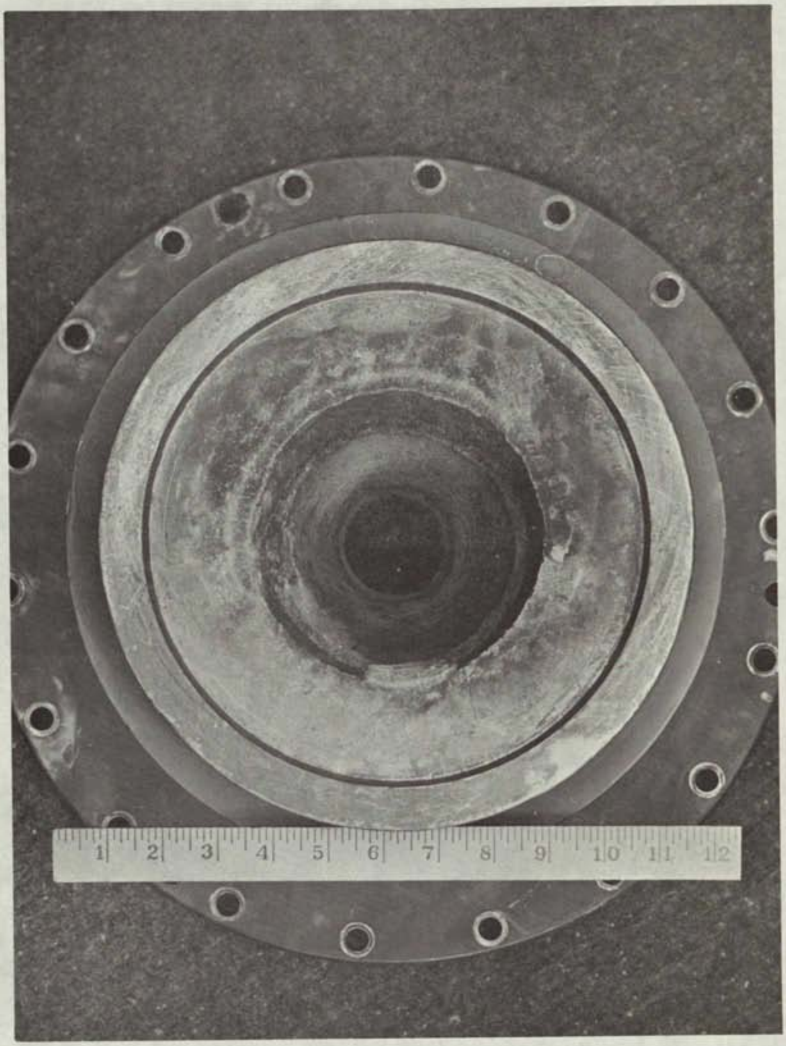


Figure 26. Aft End TU-622 Test Nozzle, LCCM-4120 (Graphite Phenolic)

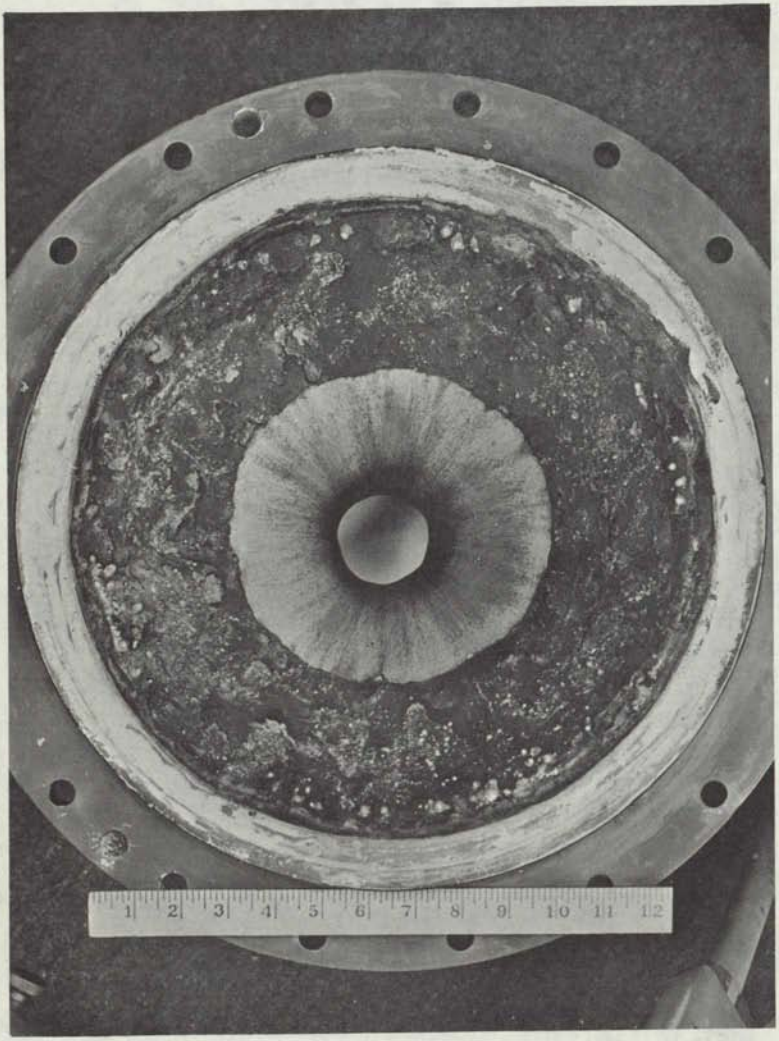


Figure 27. Forward End TU-622 Test Nozzle, SP-8030-96 (Silica Cloth Phenolic)

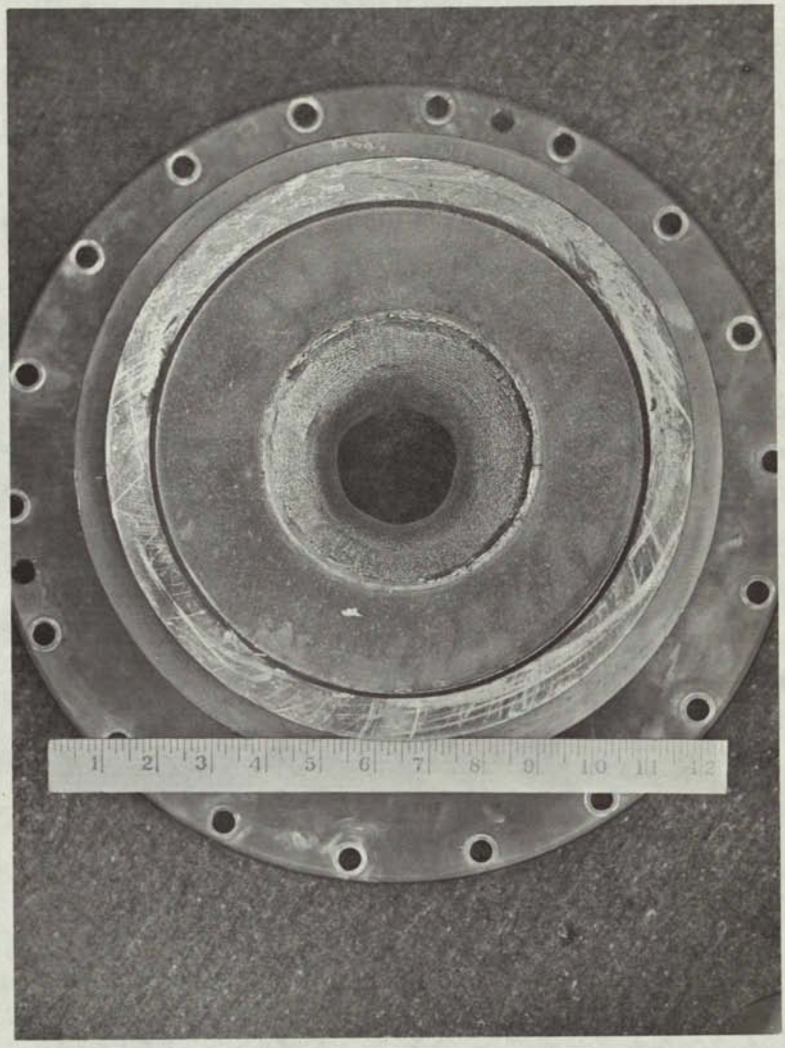


Figure 28. Aft End TU-622 Test Nozzle,
SP-8030-96 (Silica Cloth Phenolic)

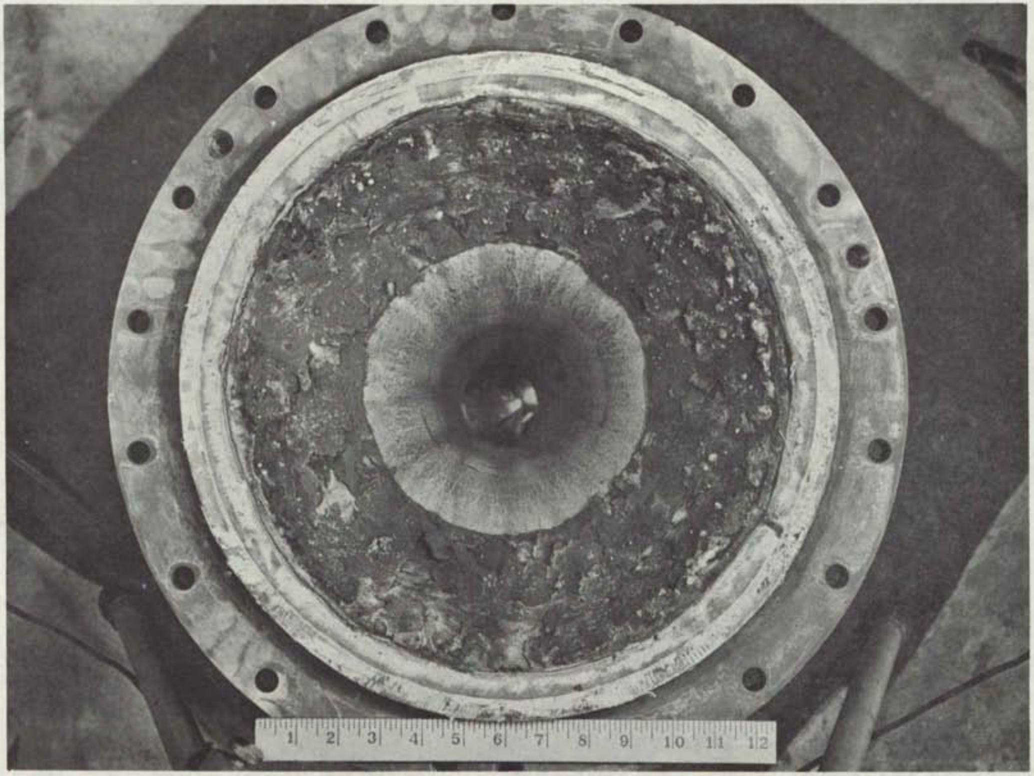


Figure 29. Forward End TU-622 Test Nozzle, MXS-198 (Silica-Epoxy Novolac) Inlet, Silica-Phenolic Split Throat, LCCM-2610 Dry (Graphite-Phenolic) Exit Cone

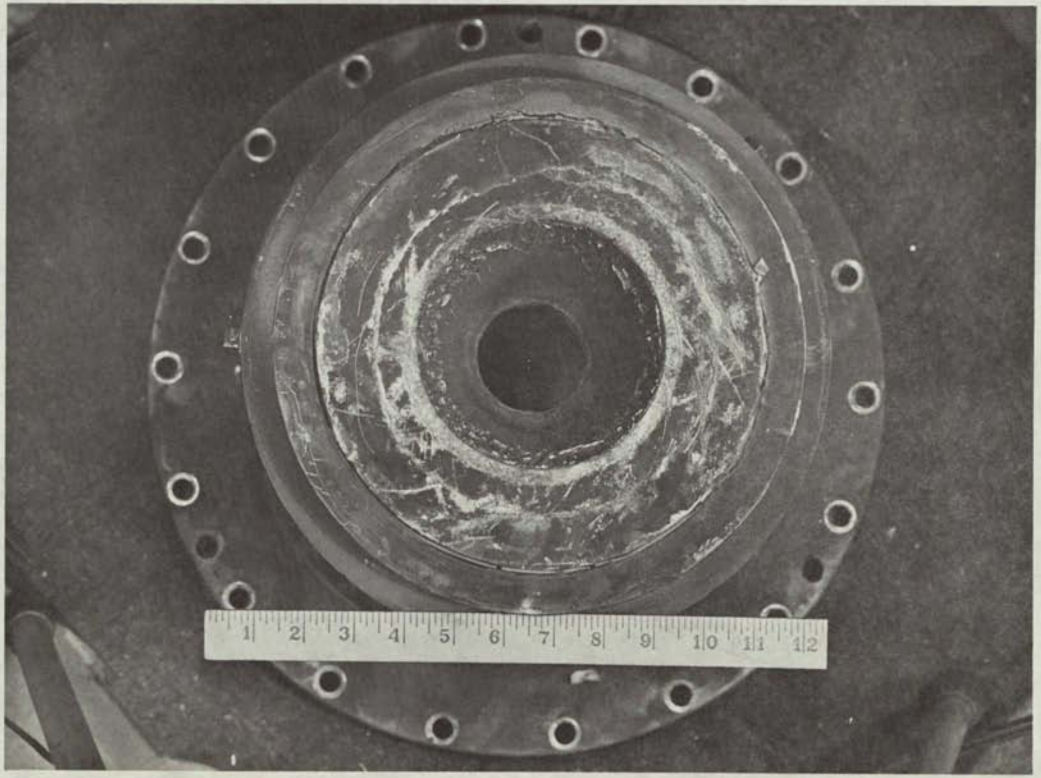


Figure 30. Aft End TU-622 Test Nozzle, MXS-198 (Silica-Epoxy Novolac) Inlet, Silica-Phenolic Split Throat, LCCM-2610 Dry (Graphite-Phenolic) Exit Cone

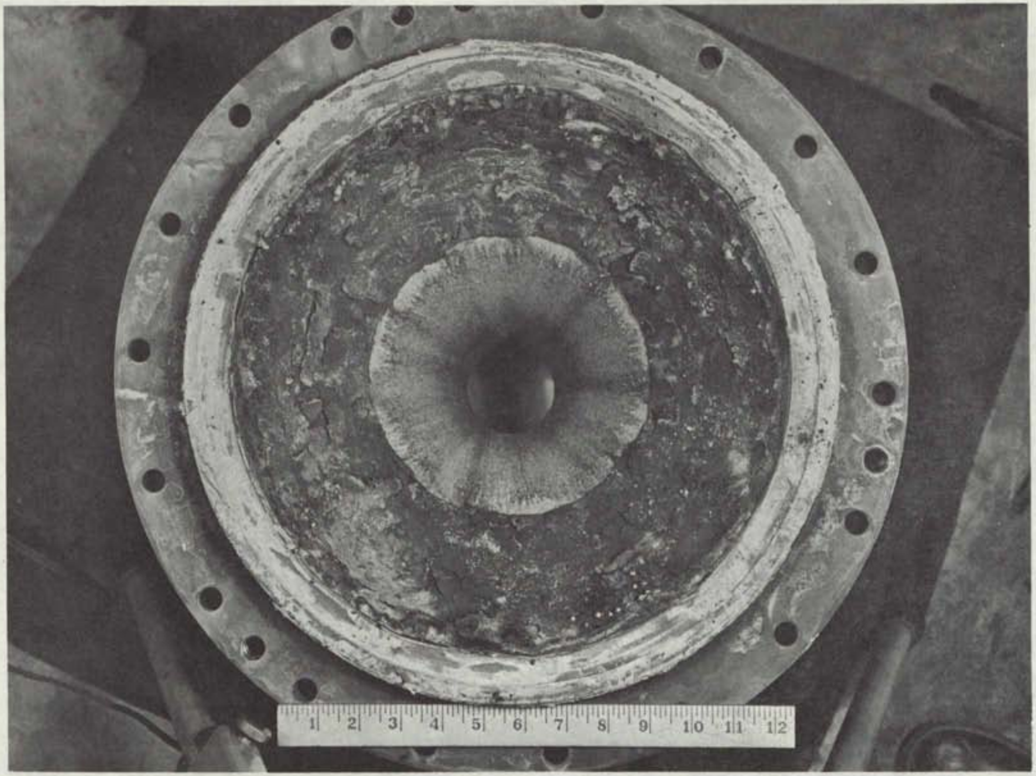


Figure 31. Forward End TU-622 Test Nozzle, 23-RPD (Cork Asbestos-Phenolic)

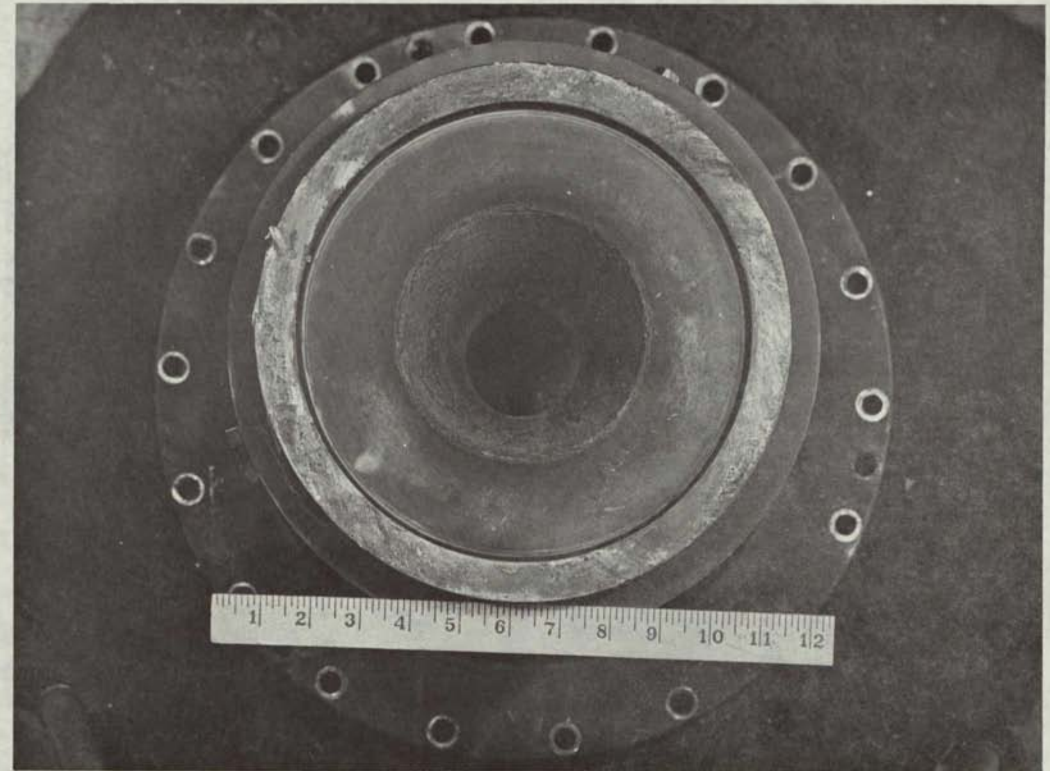


Figure 32. Aft End TU-622 Test Nozzle, 23-RPD (Cork Asbestos-Phenolic)

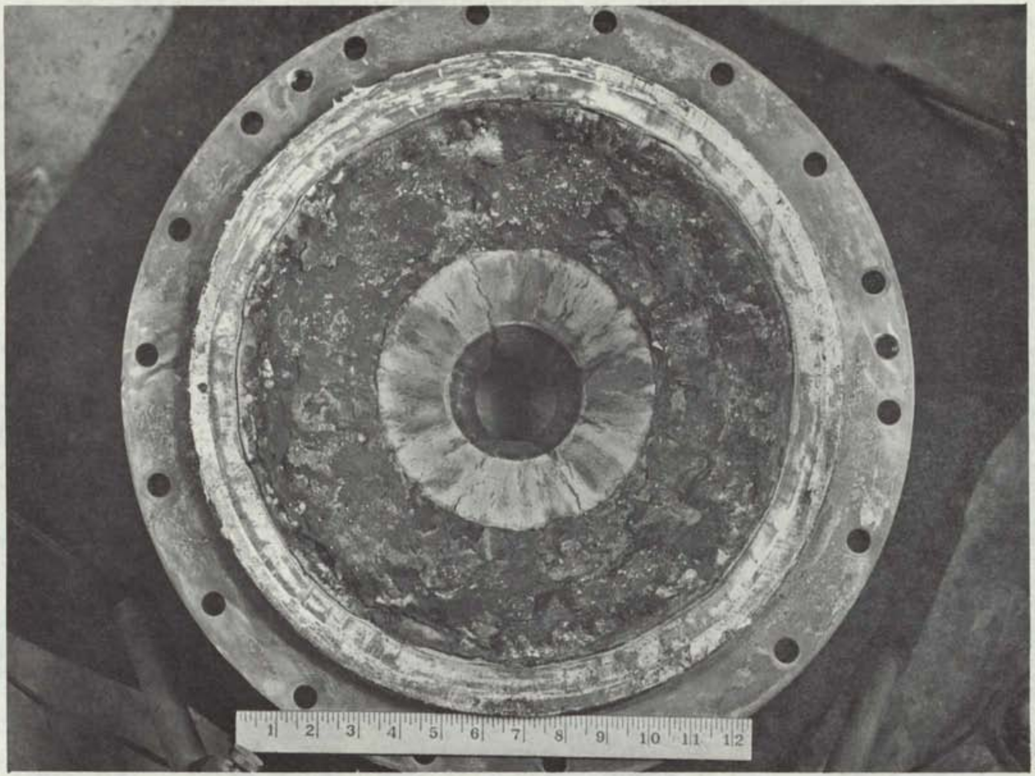


Figure 33. Forward End TU-622 Test Nozzle, SMS-21 (Paper-Phenolic)

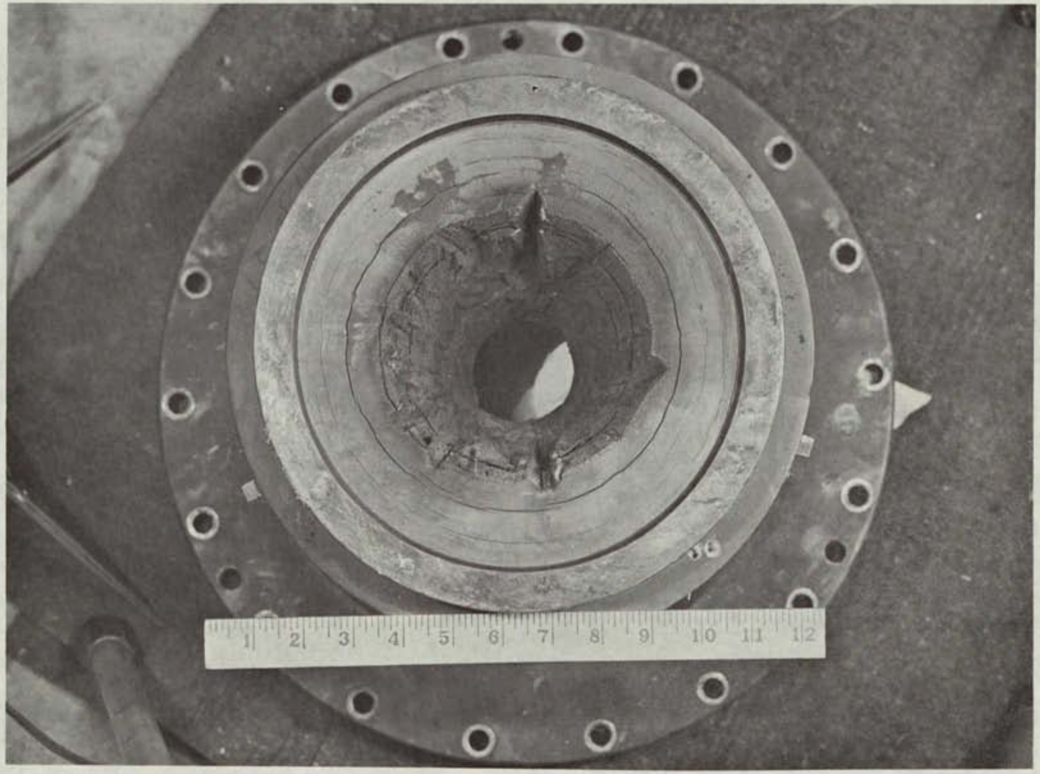


Figure 34. Aft End TU-622 Test Nozzle, SMS-21 (Paper-Phenolic)

WEB TIME AVG PRESSURE	-	466 PSIA
WEB TIME	-	33.2 SEC
TEST MATERIAL	-	LCCM-2610
AVG BALLISTIC EROSION	-	2.15 MILS/SEC
AVG INITIAL THROAT DIAMETER	-	1.740 IN.
AVG FINAL THROAT DIAMETER	-	1.883 IN.

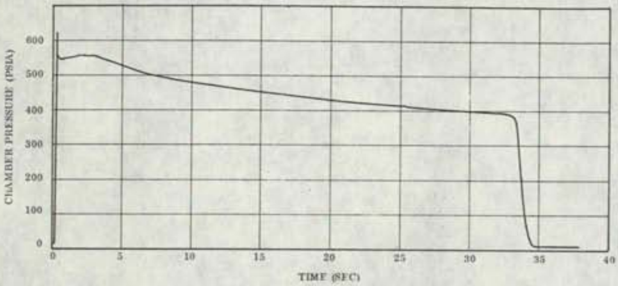


Figure 35. TU-622.01 Motor Pressure-Time Record

WEB TIME AVG PRESSURE	-	458 PSIA
WEB TIME	-	33.4 SEC
TEST MATERIAL	-	4C-1686
AVG BALLISTIC EROSION	-	3.28 MILS/SEC
AVG INITIAL THROAT DIAMETER	-	1.740 IN.
AVG FINAL THROAT DIAMETER	-	1.959 IN.

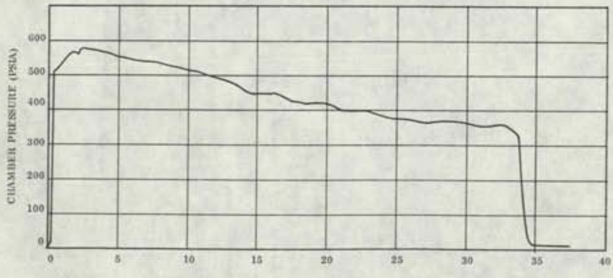


Figure 36. TU-622.02 Motor Pressure-Time Record

24535-51

TEST MATERIAL
INLET, THROAT - WB-8251
EXIT - LCCM-2610X SEGMENTED
WEB TIME - 39.4 SEC
AVG WEB PRESSURE - 312.9 PSIA
AVG INITIAL THROAT DIAMETER - 1.744 IN.
AVG FINAL THROAT DIAMETER - 2.2455 IN.
AVG BALLISTIC EROSION RATE - 6.363 MILS/SEC

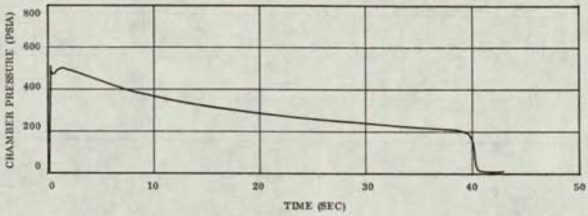


Figure 37 . TU-622.03 Motor Pressure-Time Record

WEB TIME AVG PRESSURE - 397 PSIA
WEB TIME - 35.3 SEC
TEST MATERIAL - SP-8057
AVG BALLISTIC EROSION - 4.62 MILS/SEC
AVG INITIAL THROAT DIAMETER - 1.740 IN.
AVG FINAL THROAT DIAMETER - 2.066 IN.

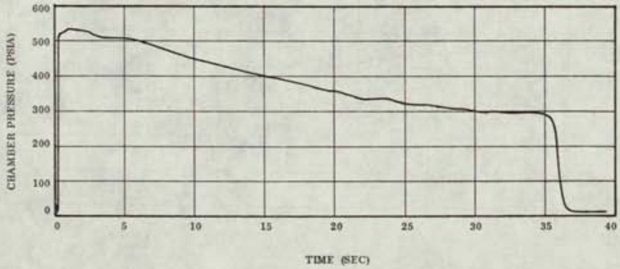


Figure 38 . TU-622.04 Motor Pressure-Time Record

24535-52

TEST MATERIAL
INLET AND THROAT - MXSC-198
EXIT CONE - LCCM-2610 SEGMENTED
WEB TIME - 37.55 SEC
AVG WEB PRESSURE - 343.2 PSIA
AVG INITIAL THROAT DIAMETER - 1.741 IN.
AVG FINAL THROAT DIAMETER - 2.2097 IN.
AVG BALLISTIC EROSION RATE - 6.24 MILS/SEC

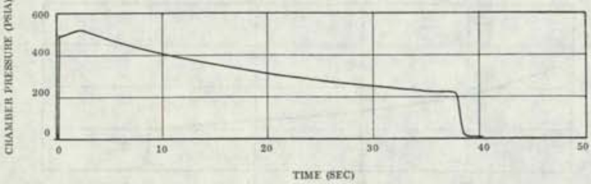


Figure 39 . TU-622.05 Motor Pressure-Time Record

WEB TIME AVG PRESSURE - 395 PSIA
WEB TIME - 35.3 SEC
TEST MATERIAL - LCCM-4120
AVG BALLISTIC EROSION - 3.85 MILS/SEC
AVG INITIAL THROAT DIAMETER - 1.748 IN.
AVG FINAL THROAT DIAMETER - 2.019 IN.

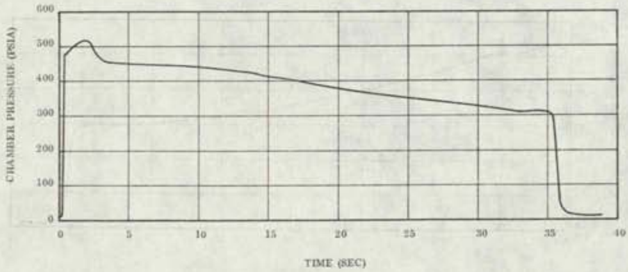


Figure 40 . TU-622.06 Motor Pressure-Time Record

24535-53

WEB TIME AVG PRESSURE - 371 PSIA
WEB TIME - 37.9 SEC
TEST MATERIAL - SP-8030-96

AVG BALLISTIC EROSION - 13.2 MILS/SEC
AVG INITIAL THROAT DIAMETER - 1.415
AVG FINAL THROAT DIAMETER - 2.416

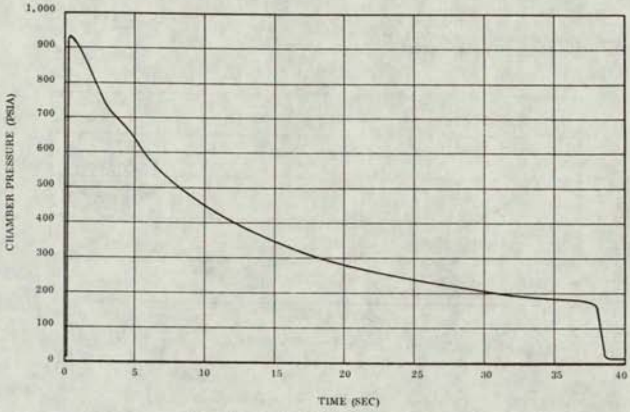


Figure 41 . TU-622.07 Motor Pressure-Time Record

TEST MATERIAL
INLET - MXSC-198
EXIT - LCCM-2610X
THROAT - MX-2600
ASTRO/140 P

MODIFIED CONTOUR

WEB TIME - 38.5 SEC
AVG WEB PRESSURE - 362.6 PSIA
AVG INITIAL THROAT DIAMETER - 1.418
*AVG FINAL THROAT DIAMETER - 2.33
*AVG BALLISTIC EROSION RATE - 11.84 MILS/SEC

AVG APPARENT EROSION RATE ≈ 13.20 B MILS/SEC
(SILICA EROSION RATE
AVERAGE DIA = 2.435)

*THROAT ACTUALLY MOVED AFT OUT OF THE SILICA INTO THE LCCM MATERIAL AND SMALLEST DIAMETER MEASURED HERE WAS 2.33.

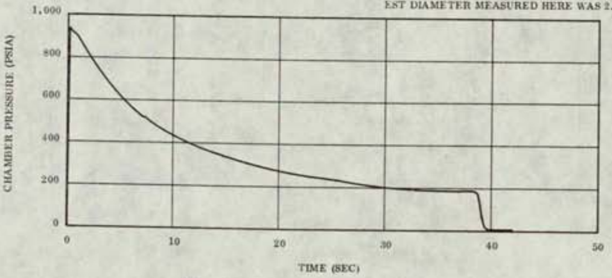


Figure 42 . TU-622.08 Motor Pressure-Time Record

24535-55

TEST MATERIAL - 23-RPD
WEB TIME - 40.6 SEC
AVG WEB PRESSURE - 316.3
AVG INITIAL THROAT DIAMETER - 1.421
AVG FINAL THROAT DIAMETER - 2.5742
AVG BALLISTIC EROSION RATE - 14.702 MILS/SEC

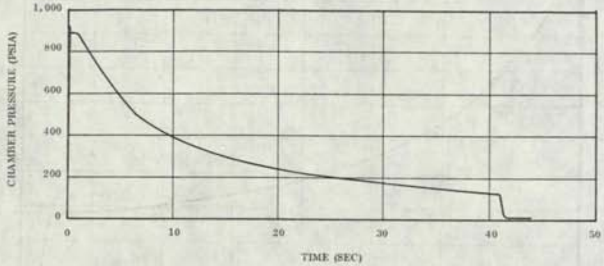


Figure 43. TU-622.09 Motor Pressure-Time Record

TEST MATERIAL - SMS-21
WEB TIME - 39.35 PSIA
AVG WEB PRESSURE - 324.9 PSIA
AVG INITIAL THROAT DIAMETER - 1.410
AVG FINAL THROAT DIAMETER - 2.3692
AVG BALLISTIC EROSION RATE - 12.071 MILS/SEC

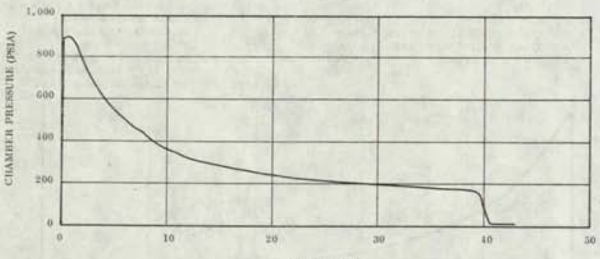


Figure 44. TU-622.10 Motor Pressure-Time Record

24535-54

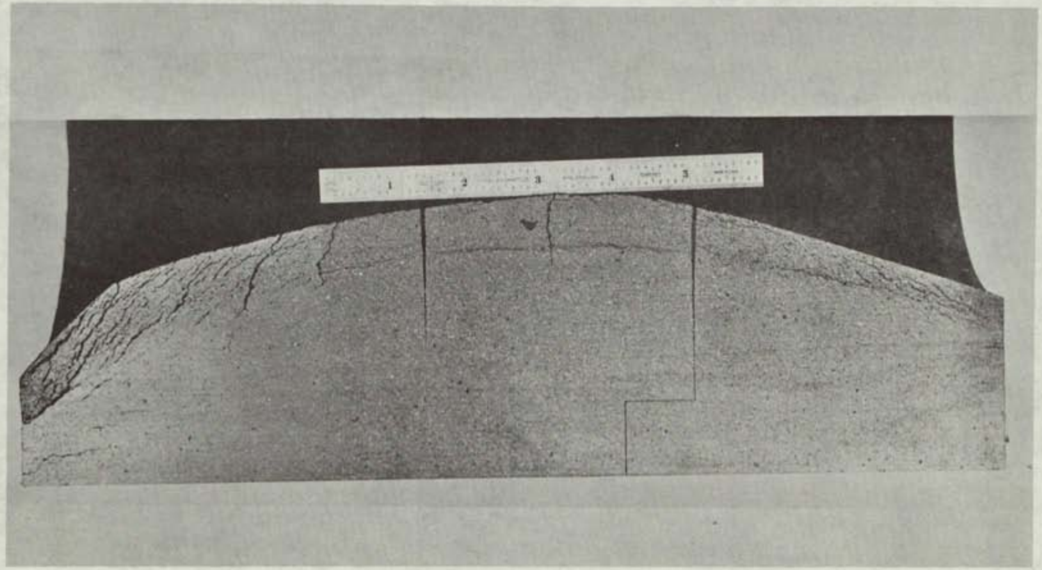


Figure 45. Sectioned TU-622 Test Nozzle, LCCM-2610 (Graphite Phenolic)

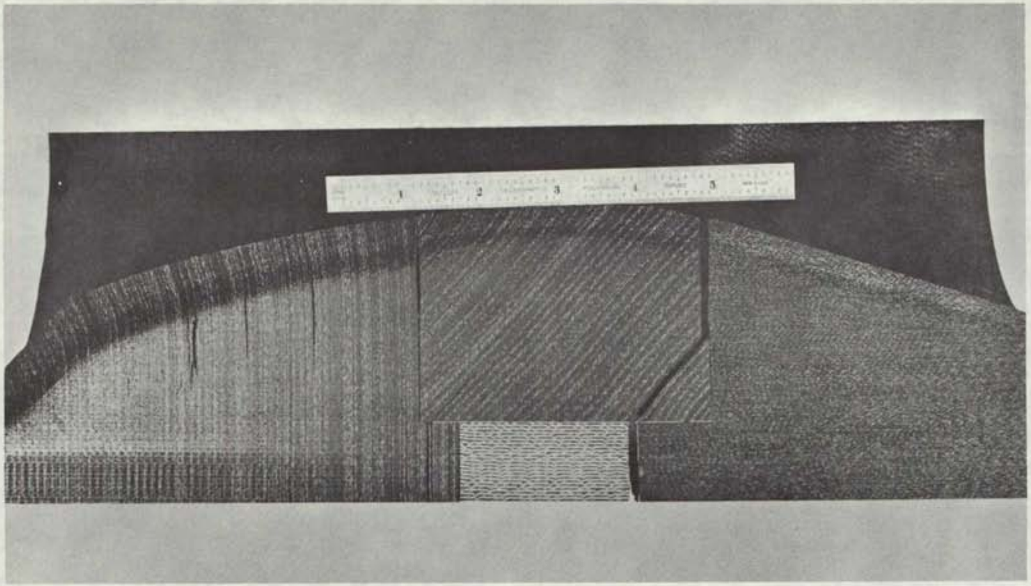


Figure 46. Sectioned TU-622 Test Nozzle, 4C-1686 (Carbon Cloth Polyphenylene)

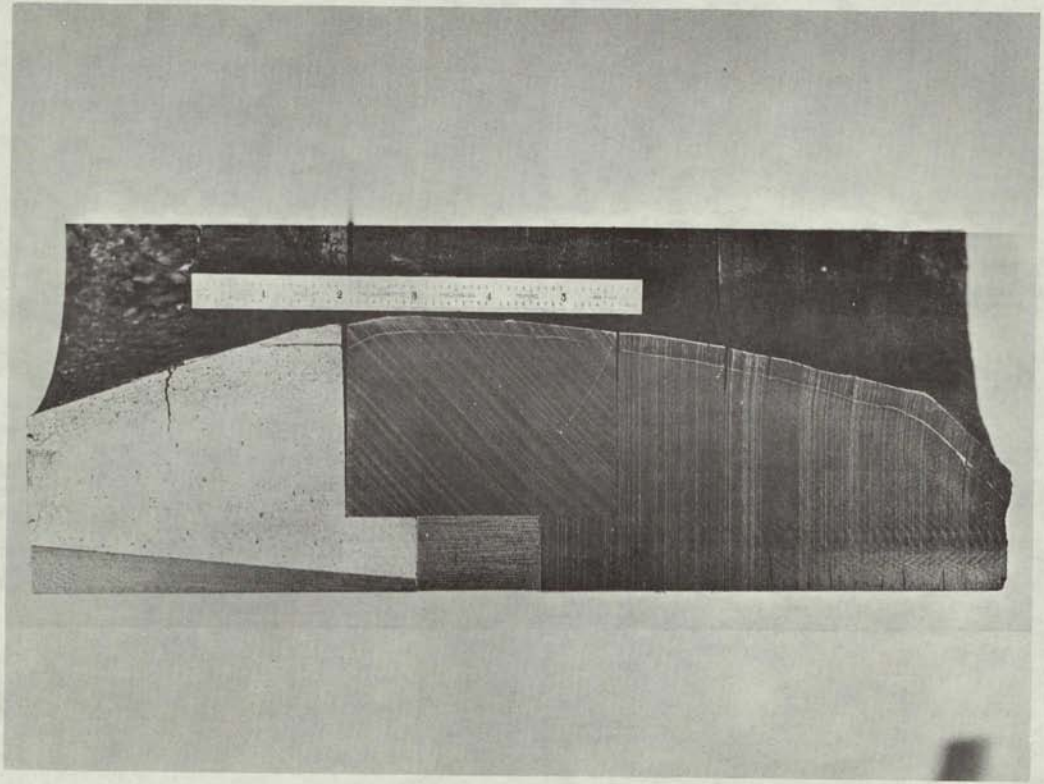


Figure 47. Sectioned TU-622 Test Nozzle, WB-8251 (Avceram C/S-Phenolic) Inlet and Throat, LCCM-2626 Dry (Graphite-Phenolic) Segmented Exit Cone

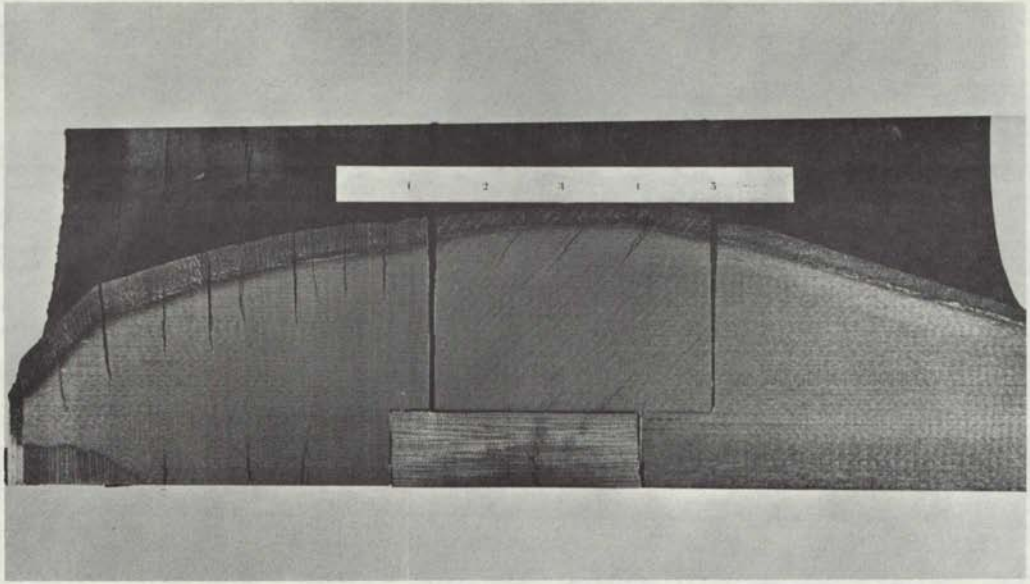


Figure 48. Sectioned TU-622 Test Nozzle, SP-8057 (Pluton H-1 Phenolic)

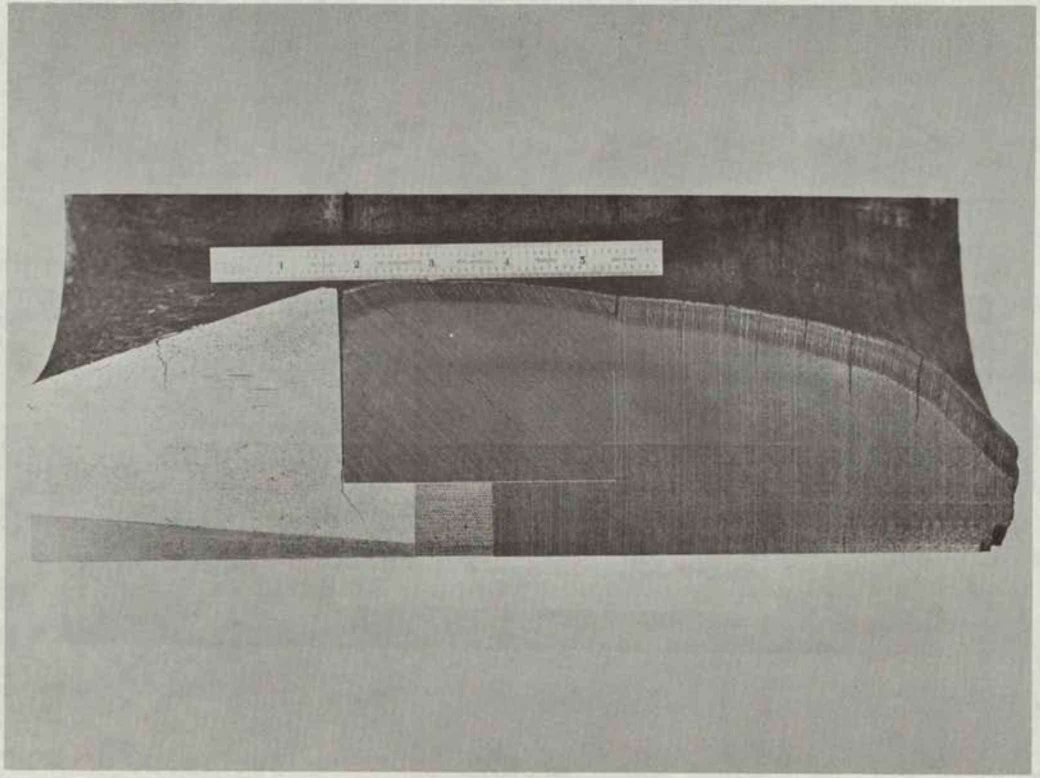


Figure 49. Sectioned TU-622 Test Nozzle, MXCS-198 (Avceram C/S-Epoxy Novolac) Inlet and Throat, LCCM-2610 (Graphite-Phenolic) Segmented Exit Cone

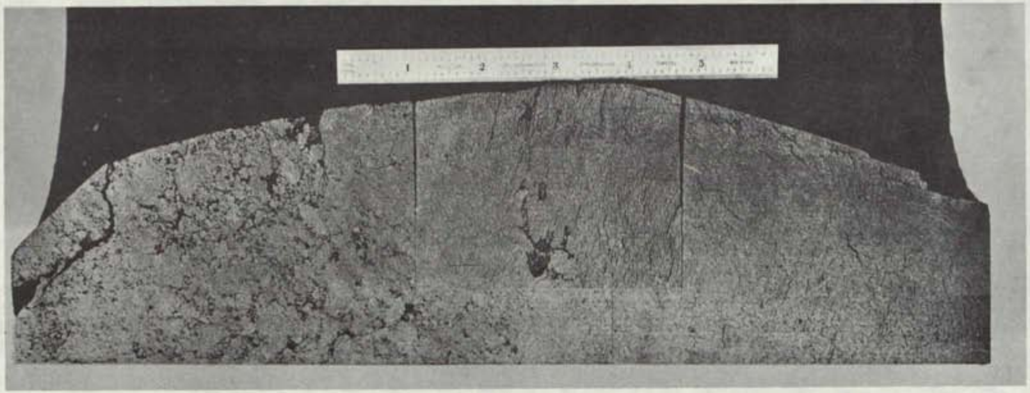


Figure 50. Sectioned TU-622 Test Nozzle, LCCM-4120 (Graphite Phenolic)

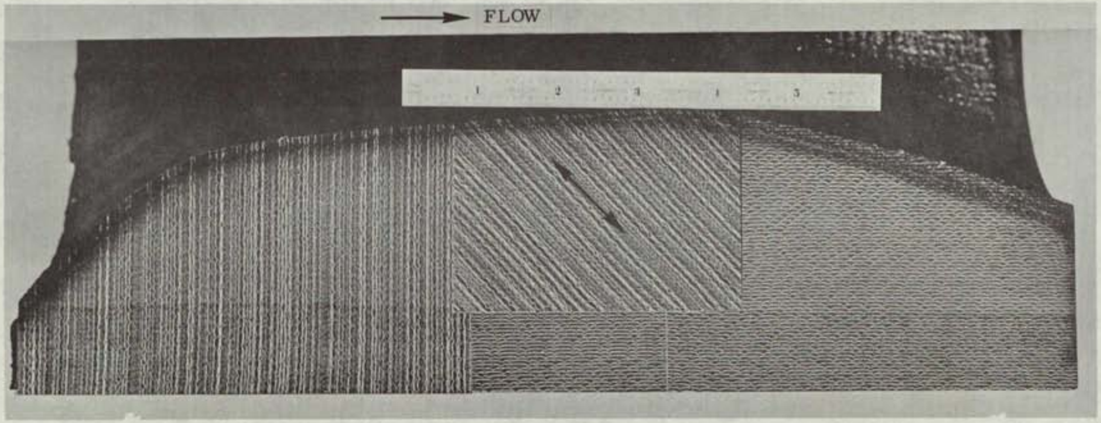


Figure 51. Sectioned TU-622 Test Nozzle, SP-8030-96 (Silica Cloth Phenolic)

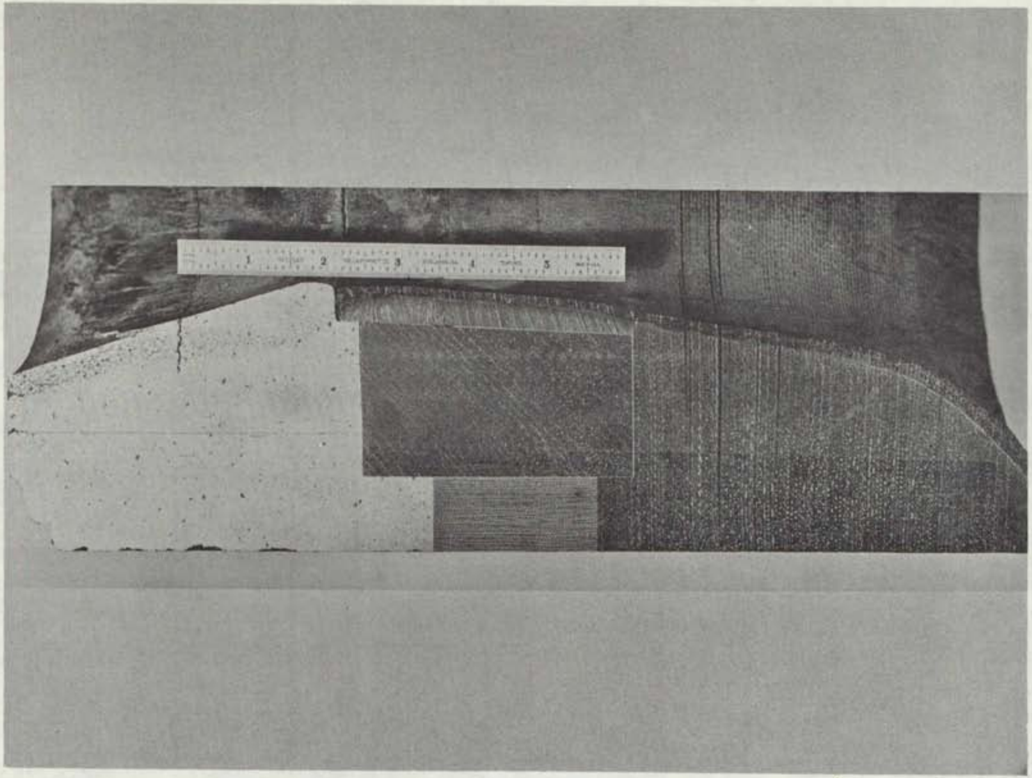


Figure 52. Sectioned TU-622 Test Nozzle, MXS-198 (Silica-Epoxy Novolac) Inlet, Silica-Phenolic Split Throat, LCCM-2626 Dry (Graphite-Phenolic) Exit Cone

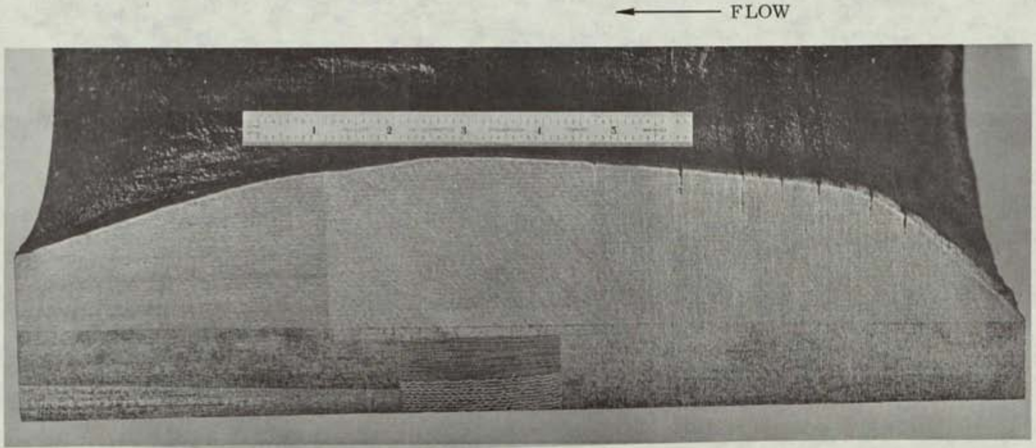


Figure 53. Sectioned TU-622 Test Nozzle, 23-RPD (Asbestos Cork-Phenolic)

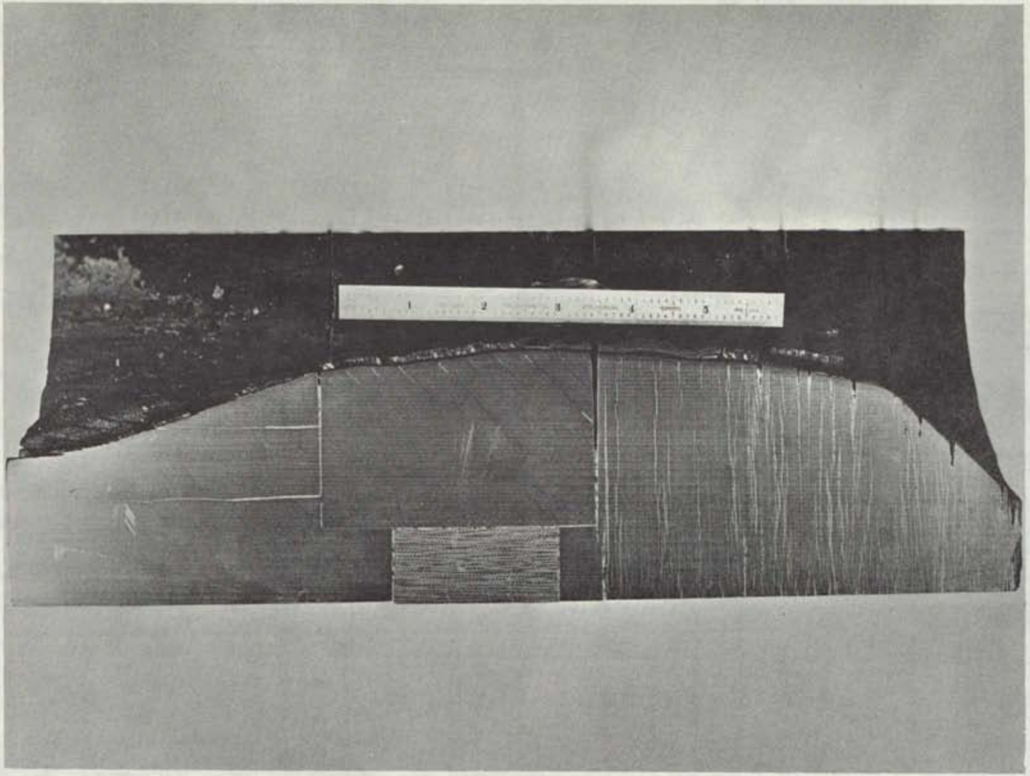


Figure 54. Sectioned TU-622 Test Nozzle, SMS-21 (Paper-Phenolic)

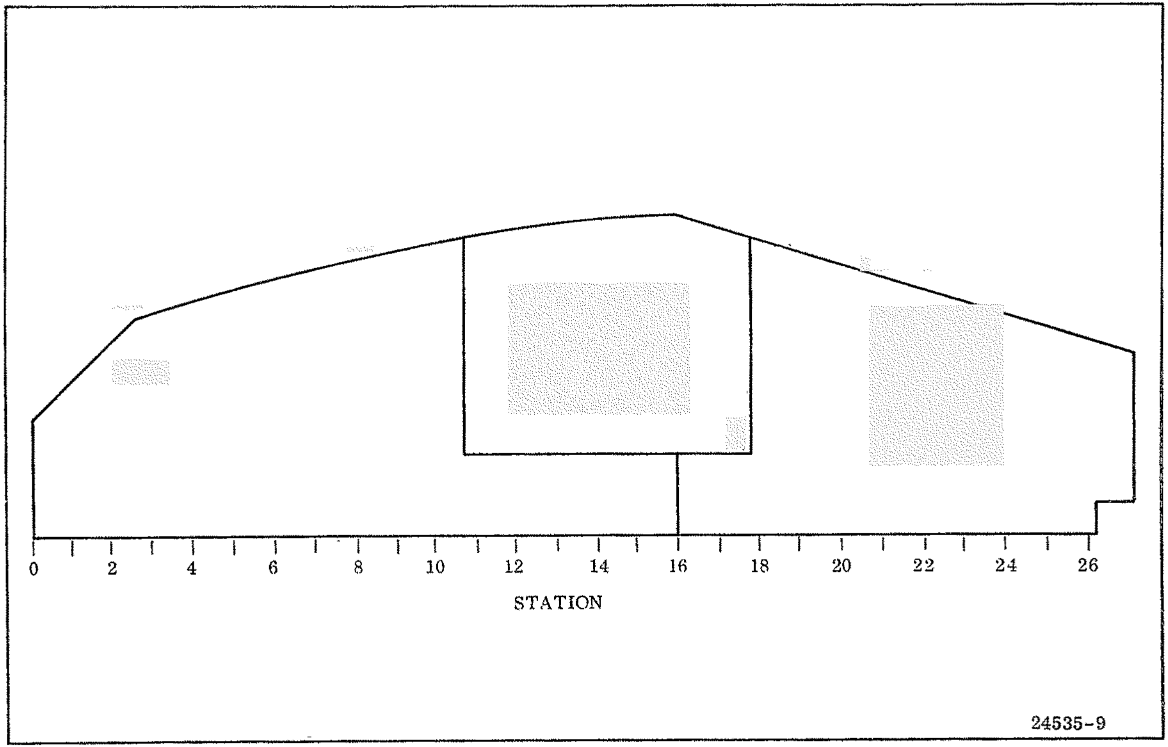


Figure 55. TU-622 Nozzle Cross Section

TABLE 15

TU-622 NOZZLE DATA, LCCM-2610

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
26	2.35	2.38	1.86	+0.03	0.49	+
25	2.50	2.54	2.08	+0.04	0.42	+
24	2.66	2.70	2.25	+0.04	0.41	+
23	2.79	2.85	2.46	+0.06	0.33	+
22	2.98	3.00	2.58	+0.02	0.40	+
21	3.14	3.16	2.68	+0.02	0.46	+
20	3.30	3.33	2.82	+0.03	0.48	+
19	3.46	3.44	2.92	0.02	0.54	0.60
18	3.60	3.60	2.96	0.00	0.64	0.00
17	3.78	3.70	3.02	0.08	0.76	2.40
16	3.89	3.76	3.06	0.13	0.83	3.91
15	3.90	3.76	3.08	0.14	0.82	4.22
14	3.87	3.77	3.08	0.10	0.79	3.01
13	3.84	3.72	3.04	0.12	0.80	3.61
12	3.80	3.68	3.04	0.12	0.76	3.61
11	3.74	3.62	3.00	0.12	0.74	3.61
10	3.66	3.56	2.94	0.10	0.72	3.01
9	3.58	3.50	2.86	0.08	0.72	2.40
8	3.48	3.40	2.78	0.08	0.70	2.40
7	3.36	3.28	2.70	0.08	0.66	2.40
6	3.24	3.16	2.56	0.08	0.68	2.40
5	3.11	3.08	2.42	0.03	0.69	0.90
4	2.94	2.92	2.20	0.02	0.74	0.60
3	2.79	2.76	1.96	0.03	0.83	0.90
2	2.45	2.44	1.60	0.01	0.85	0.30
1	1.96	2.00	1.20	+0.04	0.76	+
0	1.46	1.46	0.90	0.00	0.56	0.00

BURNING TIME 33.2 SEC

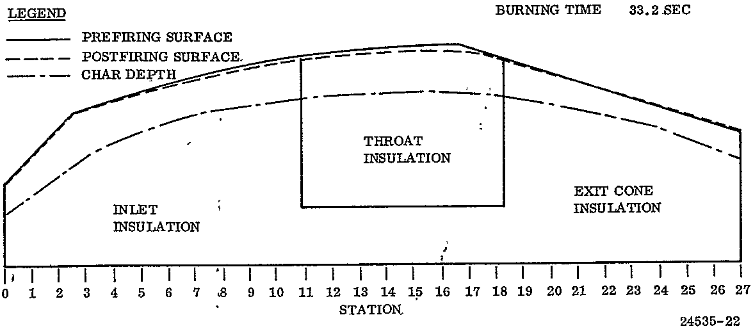


TABLE 16

TU-622 NOZZLE DATA, 4C-1686

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
26	2.35	2.40	2.10	+0.05	0.25	+
25	2.50	2.54	2.27	+0.04	0.23	+
24	2.66	2.74	2.50	+0.08	0.16	+
23	2.79	2.86	2.62	+0.07	0.17	+
22	2.98	3.04	2.74	+0.06	0.24	+
21	3.14	3.20	2.90	+0.06	0.24	+
20	3.30	3.31	3.04	+0.01	0.26	+
19	3.46	3.48	3.16	+0.02	0.30	+
18	3.60	3.60	3.26	0.00	0.34	0.00
17	3.78	2.70	3.34	0.08	0.44	2.39
16	3.89	3.74	3.40	0.15	0.49	4.49
15	3.90	3.74	3.46	0.16	0.44	4.79
14	3.87	3.72	3.46	0.15	0.41	4.49
13	3.84	3.70	3.44	0.14	0.40	4.19
12	3.80	3.66	3.40	0.14	0.40	4.19
11	3.74	3.64	3.32	0.10	0.42	2.99
10	3.66	3.58	3.24	0.08	0.42	2.39
9	3.58	3.50	3.10	0.08	0.48	2.39
8	3.48	3.38	3.04	0.10	0.44	2.99
7	3.36	3.30	3.00	0.06	0.36	1.79
6	3.24	3.19	2.80	0.05	0.44	1.50
5	3.11	3.06	2.66	0.05	0.45	1.50
4	2.94	2.92	2.50	0.02	0.44	0.60
3	2.79	2.76	2.34	0.03	0.45	0.90
2	2.45	2.58	2.10	+0.13	0.35	+
1	1.96	2.06	1.70	+0.10	0.26	+
0	1.46	--	--	--	--	--

BURNING TIME 33.4 SEC

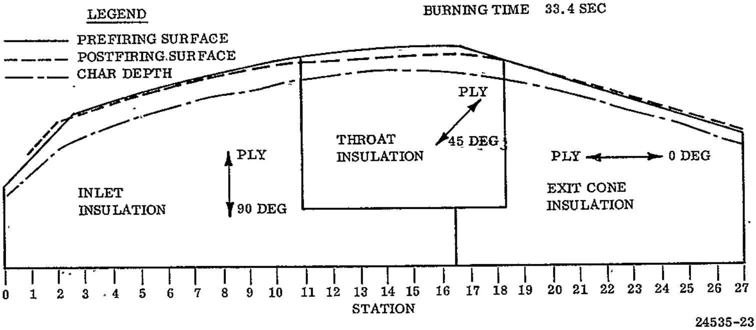


TABLE 17

TU-622 NOZZLE DATA, WB-8251 INLET AND THROAT, LCCM-2626 DRY SEGMENT EXIT

STATION NO.	CONTOUR			MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
	INITIAL	EROSION	CHAR			
26	2.35	2.40	--	+0.05	--	+
25	2.50	2.54	--	+0.04	--	+
24	2.66	2.70	--	+0.04	--	+
23	2.79	2.88	--	+0.09	--	+
22	2.98	3.08	--	+0.10	--	+
21	3.14	3.19	--	+0.05	--	+
20	3.30	3.34	--	+0.04	--	+
19	3.46	3.48	--	+0.02	--	+
18	3.60	3.56	--	0.04	--	--
17	3.78	3.61	3.36	0.17	0.42	4.31
16	3.89	3.62	3.40	0.27	0.49	6.85
15	3.90	3.58	3.40	0.32	0.50	8.12
14	3.87	3.56	3.38	0.31	0.49	7.87
13	3.84	3.54	3.34	0.30	0.50	7.61
12	3.80	3.49	3.30	0.31	0.50	7.86
11	3.74	3.43	3.24	0.31	0.50	7.86
10	3.66	3.38	3.10	0.28	0.56	7.11
9	3.58	3.32	3.04	0.26	0.54	6.60
8	3.48	3.22	2.96	0.26	0.52	6.60
7	3.36	3.10	2.84	0.26	0.52	6.60
6	3.24	3.00	2.72	0.24	0.52	6.09
5	3.11	2.84	2.60	0.27	0.51	6.85
4	2.94	2.76	2.46	0.18	0.48	4.57
3	2.79	2.64	2.30	0.15	0.49	3.81
2	2.45	2.34	1.98	0.11	0.47	2.79
1	1.96	1.86	1.52	0.10	0.44	2.54
0	1.46	--	--	--	--	--

BURNING TIME 39.4 SEC

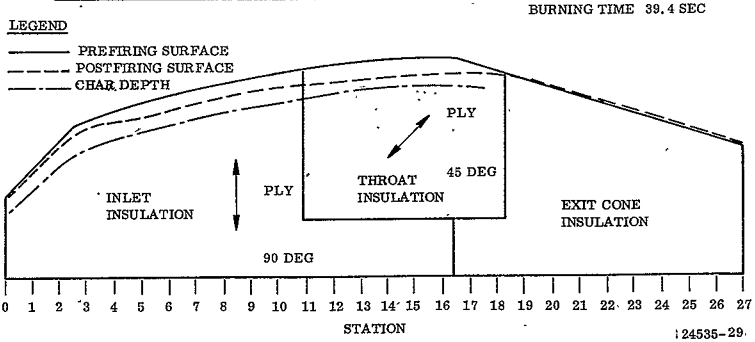


TABLE 18

TU-622 NOZZLE DATA, SP-8057

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE MILS/SEC
26	2.35	2.42	2.24	+0.07	0.11	+
25	2.50	2.60	2.42	+0.10	0.08	+
24	2.66	2.76	2.54	+0.10	0.12	+
23	2.79	2.90	2.64	+0.11	0.15	+
22	2.98	3.04	2.78	+0.06	0.20	+
21	3.14	3.20	2.96	+0.06	0.18	+
20	3.30	3.32	3.06	+0.02	0.24	+
19	3.46	3.42	3.16	0.04	0.30	1.13
18	3.60	3.58	3.26	0.02	0.34	0.57
17	3.78	3.70	3.38	0.08	0.40	2.27
16	3.89	3.70	3.42	0.19	0.47	5.38
15	3.90	3.66	3.40	0.24	0.50	6.80
14	3.87	3.64	3.38	0.23	0.49	6.52
13	3.84	3.60	3.36	0.24	0.48	6.80
12	3.80	3.58	3.30	0.22	0.50	6.23
11	3.74	3.50	3.20	0.24	0.54	6.80
10	3.66	3.42	3.06	0.24	0.60	6.80
9	3.58	3.40	3.00	0.18	0.58	5.10
8	3.48	3.32	2.92	0.16	0.56	4.53
7	3.36	3.24	2.86	0.12	0.50	3.40
6	3.24	3.10	2.72	0.14	0.52	3.97
5	3.11	3.00	2.60	0.11	0.51	3.12
4	2.94	2.82	2.40	0.12	0.54	3.40
3	2.79	2.70	2.28	0.09	0.51	2.55
2	2.45	2.42	1.90	0.03	0.55	0.85
1	1.96	1.86	1.42	0.10	0.54	2.83
0	1.46	—	—	—	—	—

BURNING TIME 35.3 SEC

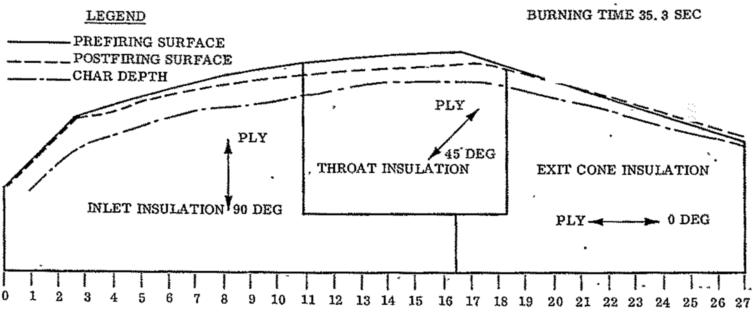


TABLE 19

TU-622 NOZZLE DATA, MXCS-198 INLET AND THROAT, LCCM-2610 WET SEGMENT EXIT

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
26	2.35	2.38	--	+0.03	--	+
25	2.50	2.54	--	+0.04	--	+
24	2.67	2.70	--	+0.03	--	+
23	2.82	2.86	--	+0.04	--	+
22	2.98	3.02	--	+0.04	--	+
21	3.12	3.18	--	+0.06	--	+
20	3.28	3.36	--	+0.08	--	+
19	3.43	3.50	--	+0.07	--	+
18	3.58	3.57	3.16	0.01	0.42	0.26
17	3.75	3.62	3.24	0.13	0.51	3.46
16	3.86	3.65	3.38	0.21	0.48	5.59
15	3.86	3.62	3.38	0.24	0.48	6.39
14	3.85	3.62	3.36	0.23	0.49	6.12
13	3.80	3.58	3.32	0.22	0.48	5.86
12	3.72	3.52	3.25	0.20	0.47	5.33
11	3.63	3.46	3.16	0.17	0.47	4.53
10	3.52	3.38	3.04	0.14	0.48	3.73
9	3.40	3.36	2.98	0.04	0.42	1.06
8	3.27	3.30	2.90	+0.03	0.37	+
7	3.16	3.22	2.80	+0.06	0.36	+
6	3.06	3.12	2.74	+0.06	0.32	+
5	2.95	3.00	2.56	+0.05	0.39	+
4	2.84	2.84	2.42	0.00	0.42	0.00
3	2.66	2.71	2.20	+0.05	0.46	+
2	2.36	2.39	1.82	+0.03	0.54	+
1	1.97	1.92	1.34	0.02	0.60	0.53
0	1.44	1.40	1.00	0.04	0.44	1.06

BURNING TIME 37.55

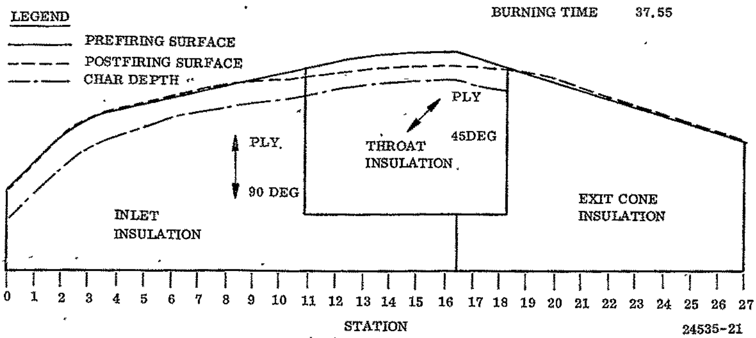


TABLE 20

TU-622 NOZZLE DATA, LCCM-4120

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
26	2.35	--	1.80	--	0.55	--
25	2.50	2.24	1.90	--	0.60	--
24	2.66	2.60	2.10	0.06	0.56	1.70
23	2.79	2.80	2.32	+0.01	0.47	+
22	2.98	3.00	2.50	+0.02	0.48	+
21	3.14	3.16	2.66	+0.02	0.48	+
20	3.30	3.30	2.76	0.00	0.54	0.00
19	3.46	3.42	2.90	0.04	0.56	1.13
18	3.60	3.58	3.04	0.02	0.56	0.56
17	3.78	3.70	3.12	0.08	0.66	2.26
16	3.89	3.74	3.14	0.15	0.75	4.25
15	3.90	3.72	3.20	0.18	0.70	5.10
14	3.87	3.70	3.10	0.17	0.77	4.81
13	3.84	3.64	3.04	0.20	0.80	5.66
12	3.80	3.60	2.94	0.20	0.86	5.66
11	3.74	3.52	2.80	0.22	0.94	6.23
10	3.66	3.48	--	0.18	--	5.10
9	3.58	3.44	--	0.14	--	3.96
8	3.48	3.36	--	0.12	--	3.40
7	3.36	3.26	--	0.10	--	2.83
6	3.24	3.14	--	0.10	--	2.83
5	3.11	3.04	--	0.07	--	1.98
4	2.94	2.92	--	0.02	--	0.56
3	2.79	2.74	--	0.05	--	1.42
2	2.45	2.46	--	+0.01	--	+
1	1.96	2.00	--	+0.04	--	+
0	1.46	1.46	--	0.00	--	0.00

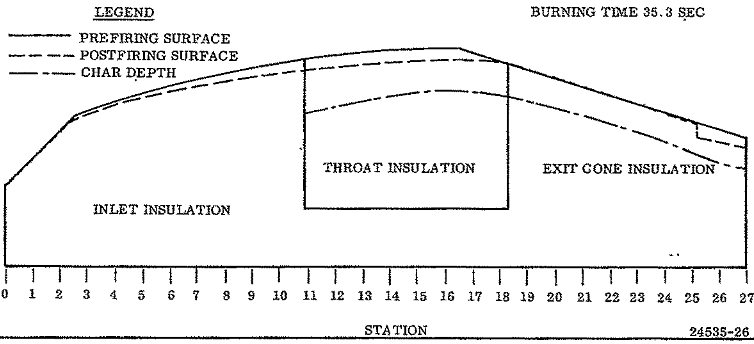


TABLE 21

TU-622 NOZZLE DATA, SP-8030-96

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
26	2.32	2.32	2.10	0.00	0.22	0.00
25	2.48	2.48	2.30	0.00	0.18	0.00
24	2.64	2.62	2.44	0.02	0.20	0.527
23	2.80	2.80	2.60	0.00	0.20	0.00
22	2.96	2.92	2.74	0.04	0.22	1.05
21	3.12	3.04	2.88	0.08	0.24	2.11
20	3.28	3.16	3.00	0.12	0.28	3.16
19	3.44	3.28	3.12	0.16	0.32	4.22
18	3.60	3.40	3.22	0.20	0.38	5.27
17	3.75	3.46	3.34	0.29	0.41	7.65
16	3.92	3.50	3.38	0.42	0.54	11.08
15	4.06	3.46	3.34	0.72	0.60	15.82
14	4.07	3.44	3.34	0.63	0.73	16.62
13	4.04	3.40	3.30	0.64	0.74	16.88
12	4.00	3.38	3.26	0.62	0.74	16.36
11	3.98	3.34	3.22	0.64	0.76	16.88
10	3.90	3.30	3.18	0.60	0.72	15.83
9	3.84	3.26	3.12	0.58	0.72	15.30
8	3.76	3.22	3.08	0.54	0.68	14.25
7	3.66	3.16	3.00	0.50	0.66	13.19
6	3.56	3.10	2.92	0.46	0.64	12.13
5	3.44	3.02	2.84	0.42	0.60	11.08
4	3.30	2.84	2.64	0.46	0.66	12.13
3	2.98	2.52	2.30	0.46	0.68	12.13
2	2.46	2.12	1.82	0.34	0.64	8.97
1	1.96	1.62	1.44	0.34	0.54	8.97
0	1.44	1.16	1.00	0.28	0.44	7.38

BURNING TIME 37.9 SEC

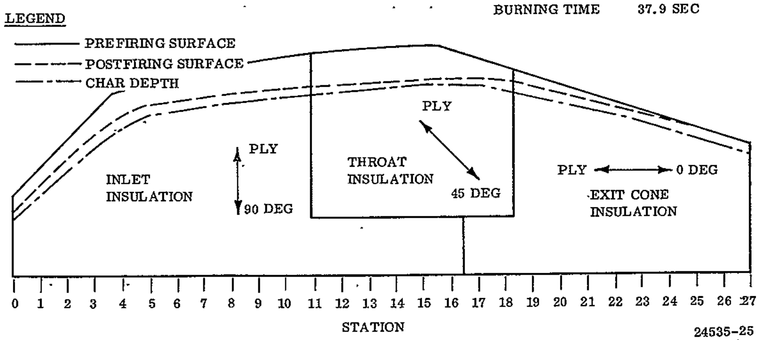


TABLE 22

TU-622 NOZZLE DATA, MXS-198 INLET, SILICA SEGMENTED THROAT, LCCM-2626 DRY EXIT

STATION NO.	CONTOUR			MATERIAL LOSS	CHAR DEPTH	EROSION RATE (MILS/SEC)
	INITIAL	EROSION	CHAR			
26	2.48	2.50	--	+0.02	--	+
25	2.64	2.66	--	+0.02	--	+
24	2.79	2.80	--	+0.01	--	+
23	2.95	3.00	--	+0.05	--	+
22	3.10	3.16	--	+0.06	--	+
21	3.25	3.30	--	+0.05	--	+
20	3.40	3.46	--	+0.06	--	+
19	3.55	3.58	--	+0.03	--	+
18	3.71	3.50	3.34	0.21	0.37	5.45
17	3.86	3.50	3.38	0.36	0.48	9.35
16	4.01	3.50	3.35	0.51	0.66	13.24
15	4.00	3.46	3.32	0.54	0.68	14.0
14	3.95	3.41	3.30	0.54	0.65	14.0
13	3.90	3.36	3.24	0.54	0.74	14.0
12	3.84	3.32	3.20	0.52	0.64	13.50
11	3.75	3.24	3.08	0.51	0.67	13.24
10	3.64	3.13	2.99	0.51	0.65	13.24
9	3.54	3.08	2.90	0.46	0.64	11.94
8	3.46	2.99	2.84	0.47	0.62	12.20
7	3.36	2.91	2.74	0.45	0.62	11.68
6	3.24	2.84	2.64	0.40	0.60	10.39
5	3.11	2.74	2.56	0.37	0.55	9.61
4	2.97	2.64	2.62	0.33	0.35	8.57
3	2.80	2.46	2.24	0.34	0.56	8.83
2	2.42	2.19	1.90	0.23	0.52	5.97
1	1.91	1.80	1.48	0.11	0.43	2.85
0	1.42	1.20	1.02	0.22	0.40	5.71

BURNING TIME 38.5 SEC

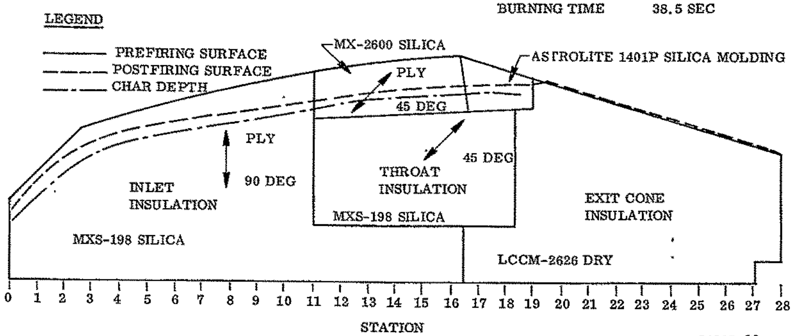
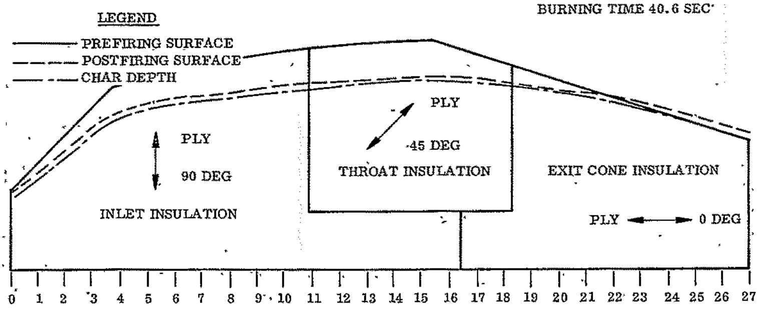


TABLE 23

TU-622 NOZZLE DATA, 23-RPD

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE MILS/SEC
26	2.32	2.46	2.32	+0.14	0.00	+
25	2.49	2.62	2.46	+0.13	0.03	+
24	2.64	2.76	2.62	+0.12	0.02	+
23	2.80	2.90	2.76	+0.10	0.04	+
22	2.96	3.00	2.90	+0.04	0.06	+
21	3.11	3.10	3.04	0.01	0.07	0.24
20	3.28	3.16	3.12	0.12	0.16	2.95
19	3.44	3.24	3.20	0.20	0.24	4.92
18	3.60	3.28	3.24	0.32	0.36	7.88
17	3.76	3.36	3.30	0.40	0.46	9.85
16	3.92	3.42	3.36	0.50	0.56	12.31
15	4.06	3.42	3.36	0.64	0.60	15.76
14	4.05	3.40	3.36	0.65	0.69	16.00
13	4.04	3.38	3.32	0.66	0.62	16.25
12	4.00	3.34	3.28	0.66	0.72	16.25
11	3.96	3.32	3.22	0.64	0.74	15.76
10	3.89	3.28	3.18	0.61	0.71	15.02
9	3.82	3.20	3.12	0.62	0.70	15.27
8	3.74	3.16	3.04	0.58	0.70	14.28
7	3.66	3.08	3.00	0.58	0.66	14.28
6	3.55	3.06	2.94	0.49	0.61	12.1
5	3.42	2.96	2.87	0.46	0.65	11.33
4	3.28	2.80	2.72	0.48	0.56	11.82
3	2.92	2.54	2.42	0.38	0.50	9.36
2	2.41	2.10	1.98	0.31	0.43	7.63
1	1.90	1.72	1.58	0.18	0.32	4.43
0	1.43	1.08	---	0.35	—	8.62

BURNING TIME 40.6 SEC



24535-24

TABLE 24

TU-622 NOZZLE DATA, SMS-21

STATION NO.	CONTOUR INITIAL	CONTOUR EROSION	CONTOUR CHAR	MATERIAL LOSS	CHAR DEPTH	EROSION RATE MILS/SEC
26	2.32	2.06	2.00	0.26	0.32	6.60
25	2.49	2.14	2.08	0.35	0.31	8.89
24	2.64	2.28	2.19	0.36	0.45	9.15
23	2.80	2.42	2.32	0.38	0.48	9.66
22	2.96	2.58	2.50	0.38	0.46	9.66
21	3.11	2.72	2.64	0.39	0.47	9.91
20	3.28	2.90	2.82	0.38	0.46	9.66
19	3.44	3.04	2.96	0.40	0.48	10.16
18	3.60	3.20	3.08	0.40	0.52	10.16
17	3.76	3.20	3.10	0.56	0.66	14.23
16	3.92	3.30	3.18	0.62	0.74	15.75
15	4.06	3.34	3.23	0.72	0.83	18.29
14	4.05	3.42	3.32	0.63	0.73	16.00
13	4.04	3.49	3.34	0.55	0.70	13.97
12	4.00	3.49	3.30	0.51	0.70	12.96
11	3.96	3.45	3.25	0.51	0.71	12.96
10	3.89	3.40	3.22	0.49	0.67	12.45
9	3.82	3.32	3.14	0.50	0.68	12.70
8	3.74	3.26	3.10	0.48	0.64	12.20
7	3.66	3.20	3.08	0.46	0.58	11.69
6	3.55	3.10	2.98	0.45	0.57	11.43
5	3.42	3.00	2.90	0.42	0.52	10.67
4	3.28	2.90	2.80	0.38	0.48	9.66
3	2.92	2.58	2.50	0.34	0.42	8.64
2	2.41	2.20	2.02	0.21	0.39	5.34
1	1.90	1.78	1.62	0.12	0.28	3.05
0	1.43	1.38	1.22	0.05	0.21	1.27

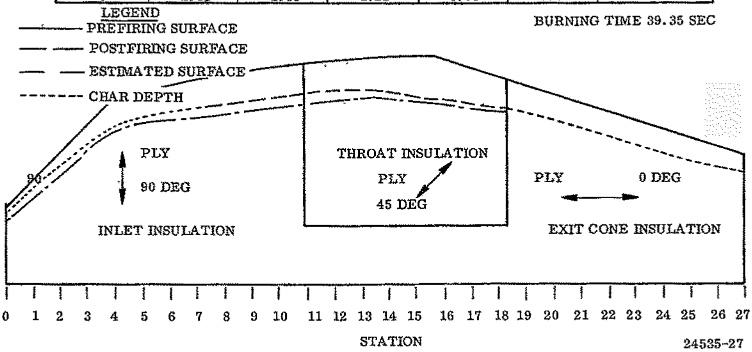
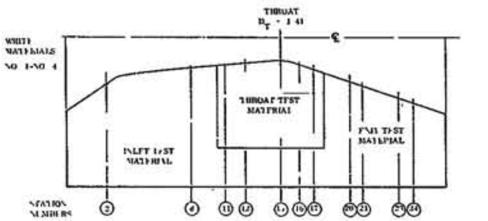
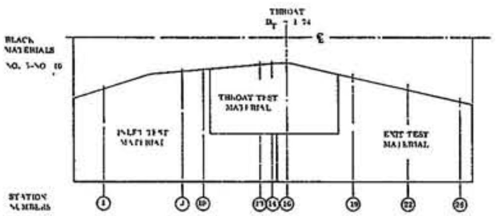


TABLE 25

TU-622 MOTOR MATERIAL PERFORMANCE





Nozzle Location with Material Erosion and Char Rates (mil/sec)

No.	Material	Rate (mil/sec)	UC	C	UC	C	UC	C	UC	C	UC	C	UC	C	UC	C
	White		Station 2 D = 4 64 ε = 10 63		Station 8 D = 2 00 ε = 2 02		Station 12 D = 1 50 ε = 1 14		Station 15 D_T = 1 41 ε = 1.0		Station 17 D = 2 03 ε = 2 05		Station 20 D = 2 95 ε = 4 35		Station 23 D = 3 ε = 7	
		Erosion	9 0	10 4	14 2	16 4	16 4	18 9	15 8	18 2	7 7	8 9	3 2	3 7	0 0	0 0
1	SP8030-96	Char	15 9	18 7	17 9	20 3	19.5	22 1	19 0	21 6	10 8	12 1	7.4	8 1	5.3	5 6
		Erosion	7 6	9 9	14 2	18 8	16 3	21 3	15 6	20 6	9 9	12 9	3 0	3 8	0 0	0 0
2	23RPD	Char	10 6	12 1	17 2	21 7	17.7	22 8	17.7	22 7	11 3	14 4	3.9	4 8	3.4	3 6
		Erosion	5 3	6 8	12 2	15 6	13 0	16 6	18 3	22 4	14 2	18 1	9 7	12 4	9 7	12 4
3	SMS-21	Char	9 9	11 6	16 3	19 9	17.6	21 6	21 1	26 3	16 8	20 9	11 7	14 5	12.2	15.7
			Station 7 D = 4.04 ε = 10 63		Station 11 D = 2 00 ε = 2 02		Station 13 D = 1 50 ε = 1 14		Station 16 D = 1 41 ε = 1 0		Station 18 D = 2 10 ε = 2 20		Station 21 D = 2 94 ε = 4 45		Station 24 D = 3.96 ε = 7.89	
		Erosion	6 0	7 0												
4	MXS-198	Char	13 5	14 9												
		Erosion			13 2	15 5	14 0[2]	16 4[2]	13 2[2]	15 2[2]						
4.	MX-2600	Char			17.4	19 9	17 7	20 2	17.1	19 8						
		Erosion									5 [illegible][2]	6 [illegible][2]				
4	Astrolite 4401P	Char									9 6	10.7				
		Erosion											0 0	0 0	0.0	0.0
4	LCCM T2610X	Char											N/A	N/A	N/A	N/A
	Black		Station 1 D = 5 68 ε = 10 65		Station 9 D = 2 40 ε = 1 89		Station 13 D = 1 85 ε = 1 13		Station 15 D ≅ 1 74 ε ≅ 1.00		Station 19 D = 2 60 ε = 2 23		Station 22 D = 3 54 ε = 4.13		Station 26 D = 4 82 ε = 7.65	
		Erosion	0 0	0 0	2 4	2.4	3 6	3 6	3 9	3 9	0 6	0 6	0 0	0 0	0.0	0.0
5	LCCM T2610	Char	24 1	24 1	21 7	21 7	24 1	24 1	25 0	25 0	16 3	16 2	12 7	12 7	15.7	15 7
		Erosion	0 0	0 0	4 0	4.6	5 7	6 5	1 3	4 9	1 1	1 3	0 0	0 0	Spalling	0 0
6	LCCM T4120	Char	N/A	N/A	N/A	N/A	23 7	23 8	21.2	22 1	15 9	16 4	14 1	14 4	15 5	15 8
		Erosion	0 0	0 0	2 4	2 4	4 2	4 2	4 5	4 5	0 0	0 0	0 0	0 0	0 0	0 0
7	4C-1686	Char	10 5	10 8	14 4	14 5	12 0	12 0	14 7	14 7	9 6	9 7	9.0	9 1	9.0	9.1
		Erosion	2 8	3 2	5 1	5 8	6 8	7 8	5 4	6 2	1 1	1 3	0 0	0 0	0 0	0 0
8	SP-8057	Char	15 3	15 9	16.4	17 3	13 6	14 7	13 3	14 2	8 6	8 8	7.4	7.6	5 1	5.3
		Erosion	2 5	3 4	6 6	9 0	7 6	10 4	6 9	9 5						
9	WB 8251	Char	11 3	13 6	13 7	16 5	12 7	15 8	12 4	15 3						
		Erosion									0 0	0 0	0 0	0 0	0 0	0 0
9	LCCM T2610X Segmented	Char									N/A	N/A	N/A	N/A	N/A	N/A
			Station 1 D = 5 68 ε = 10.65		Station 10 D = 2 30 ε = 2 07		Station 14 D = 1 85 ε = 1 13		Station 16 D ≅ 1 74 ε ≅ 1 00		Station 19 D = 2 60 ε = 2 23		Station 22 D = 3 54 ε = 4 13		Station 26 D = 4 82 ε = 7 65	
		Erosion	0 5	0 6	3 7	4 7	6 1	7 8	5 6	7 2						
10	MASC198	Char	16 0	16 7	12 8	14 2	13 0	15 0	12 8	14 7						
		Erosion									0.0		0 0	0 0	0 0	0 0
10	LCCM T2616 Segmented	Char									N/A		N/A	N/A	N/A	N/A

No.	Material	Avg Web Pressure (psia)	Throat Diameter Initial (in.)	Propellant Grain Shape	Propellant Formulation	Nozzle Type	Nozzle Shape	Web Burn Time (sec)	Erosion Press Corr Factor to Avg Press of LCCM T2610 466 psi	Erosion Dia Corr Fact to LCCM T2610 D_T = 1 419	Erosion Contour & Shape Factor	Erosion Propellant Grain Factor	Erosion Propellant Formulation Factor	Erosion Nozzle Type Factor	Material Char Corr Factor: Char Corr Factor to Avg Time of LCCM T2610
1	SP8030-96	371	1 415	End Burner	TP-H1128	Fixed External	Simple Inlet Radius 20 0 in	37.9	$\frac{0\ 543}{0\ 432}$ = 1 26	$\frac{1\ 419}{1\ 478}$ = 0 96	1 00	1 00	1 00	1.00	$\frac{10.9}{11.8}$ = 0.92
2	23RPD	316	1 421					49.6	$\frac{0\ 543}{0\ 390}$ = 1 38	$\frac{1\ 419}{1.478}$ = 0 96					$\frac{10\ 9}{12.4}$ = 0.88
3	SMS-21	325	1 410				Simple Inlet Radius 20.0 in	35.4	$\frac{0\ 543}{0\ 407}$ = 1 33	$\frac{1\ 419}{1\ 478}$ = 0 96					$\frac{10\ 9}{12\ 2}$ = 0 89
4	MXS-198														
4.	MX-2600	383	1 418	End Burner	TP-H1128 16AL/71AP/13HC	Fixed External	Compound Inlet Two Radii 30 in and 7 in.	38 5	$\frac{0.543}{0\ 445}$ = 1.22	$\frac{1\ 419}{1\ 478}$ = 0 96	Shift Station Locations to Compare Planes of Equal ID Mach No				$\frac{10.9}{12\ 0}$ = 0.91
4	Astrolite 4401P														
4	LCCM T2610X										1.00	1 00	1 00	1 00	
5	LCCM T2610	466	1 740	End Burner	TP-H1128	Fixed External	Simple Inlet Radius 20 0 in.	33 2	$\frac{0\ 543}{0\ 543}$ = 1 00	$\frac{1\ 419}{1\ 419}$ = 1 00	1.00	1 00	1.00	1 00	$\frac{10.9}{10\ 9}$ = 1 00
6	LCCM T4120	395	1 768					35 3	$\frac{0\ 543}{0\ 476}$ = 1.14	$\frac{1\ 419}{1\ 419}$ = 1 00					$\frac{10\ 9}{11\ 4}$ = 0 96
7	4C-1686	455	1 740					33 4	$\frac{0\ 543}{0\ 535}$ = 1 01	$\frac{1\ 419}{1\ 419}$ = 1 00					$\frac{10\ 9}{10\ 9}$ = 1.00
8	SP-8057	397	1 740					35 3	$\frac{0\ 543}{0\ 478}$ = 1 14	$\frac{1\ 419}{1\ 419}$ = 1 00					$\frac{10.9}{11.3}$ = 0.96
9	WB 8251														
9	LCCM T2610X Segmented	313	1 744				Simple Inlet Radius 30 0 in	39 4	$\frac{0\ 543}{0\ 395}$ = 1 37	$\frac{1\ 419}{1\ 419}$ = 1 00					$\frac{10\ 9}{12\ 2}$ = 0 89
10	MASC198	343	1 741	End Burner	TP-H1128	Fixed External	Compound Inlet Radius Two Radii 2.50 in and 13 26 in	37 6	$\frac{0\ 544}{0.425}$ = 1 28	$\frac{1\ 419}{1\ 419}$ = 1.00	1 00 Shift Station Locations to Compare Planes of Equal ID Mach No	1 00	1.00	1 00	$\frac{10\ 9}{11\ 8}$ = 0 92
10	LCCM T2616 Segmented														
		375 Avg Web Pressure						37 1 Avg Web Time							

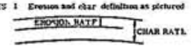
$$\text{Erosion Press Corr Factor} = \frac{\left(\frac{466}{1000}\right)^{1/1\ 25}}{\left(\frac{x}{1000}\right)^{1/1\ 25}} = \frac{0\ 543}{(\ )}$$

$$\text{Erosion Throat Dia Corr Factor} = \frac{\left(\frac{10\ 00}{1\ 74}\right)^{1/5}}{\left(\frac{10\ 00}{x}\right)^{1/5}} = \frac{1\ 419}{(\ )}$$

$$\text{Char Time Factor} = \frac{(33\ 2)^{1/1\ 47}}{(x)^{1/1\ 47}} = \frac{10\ 9}{(\ )}$$

NOTES

1. Erosion and char definition as pictured



2. Erosion rates are low since throat plane shifted aft LCCM T2610X a low erosion material
3. UC = Uncorrected
   C = Corrected
   N/A = Not Available.
4. Erosion and char thickness measured to ℄.

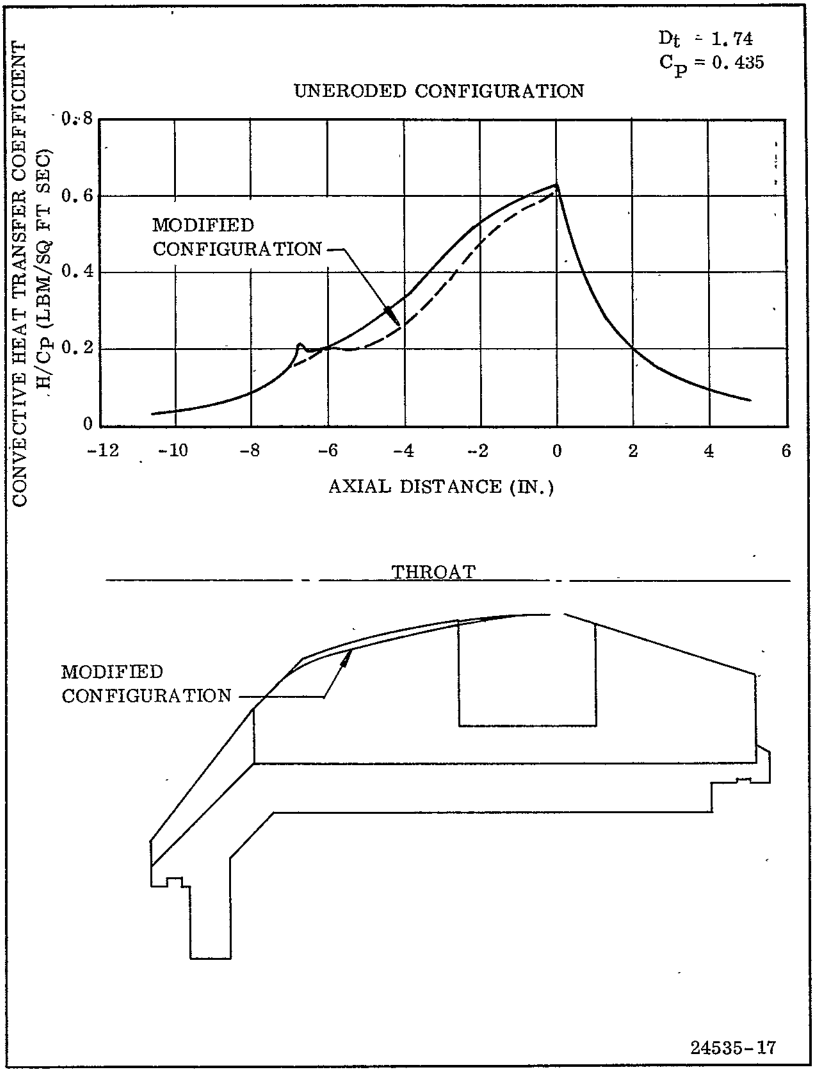


Figure 56 . TU-622 Motor Convective Heat Transfer Coefficient vs Axial Location, Carbonaceous Materials

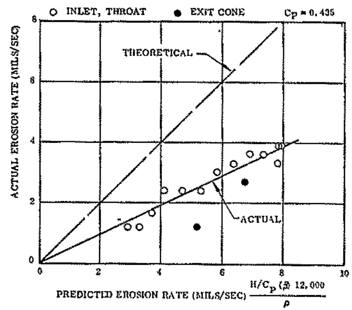


Figure 57. TU-622 Erosion Performance, LCCM-2610 (Graphite Particle Phenolic)

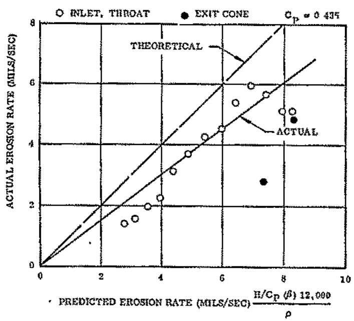


Figure 58 TU-622 Erosion Performance, LCCM-4120 (Graphite Particle Phenolic)

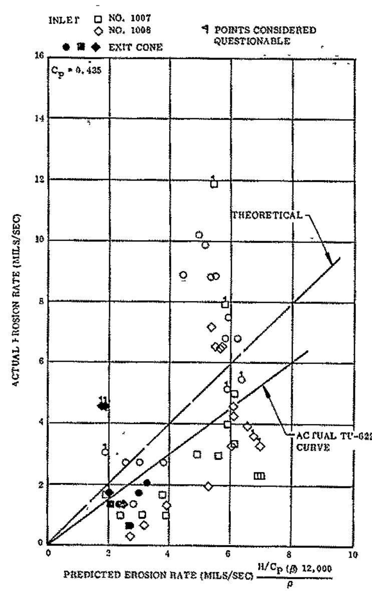


Figure 59. TU-379 Erosion Performance, LCCM-4120 (Graphite Particle Phenolic)

24535-40

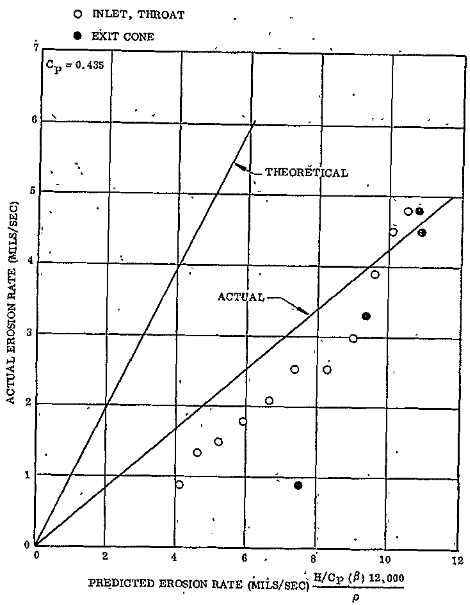


Figure 60. TU-622 Motor Erosion Performance, 4C-1686 (Carbon Cloth Polyphenylene)

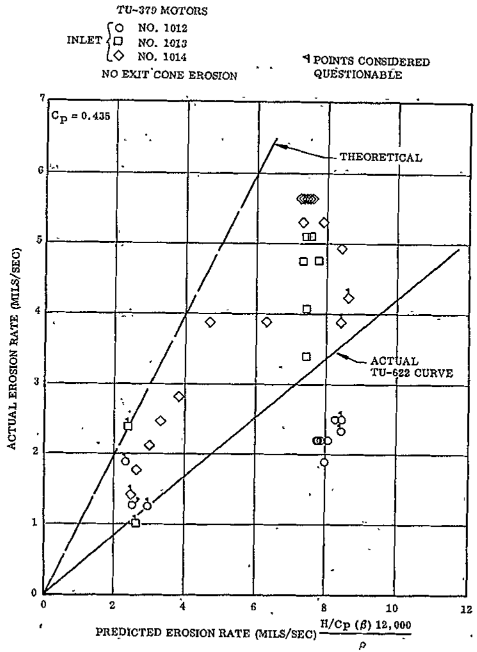


Figure 61. TU-379 Motor Erosion Performance, 4C-1686 (Carbon Cloth Polyphenylene)

24523-8

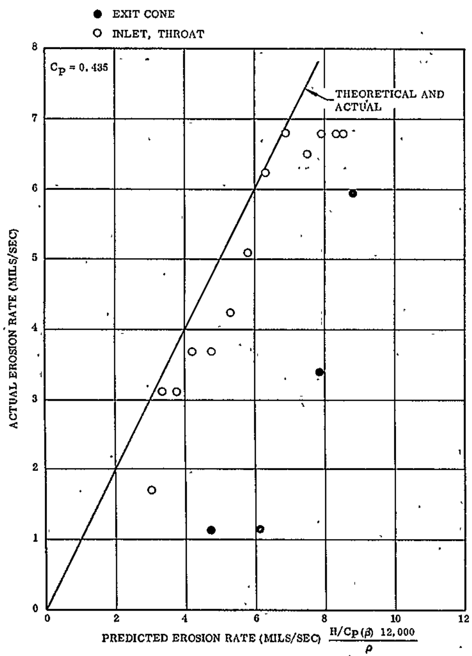


Figure 62. TU-622 Motor Erosion Performance, SP-8057 (Pluton H-1 Cloth Phenolic)

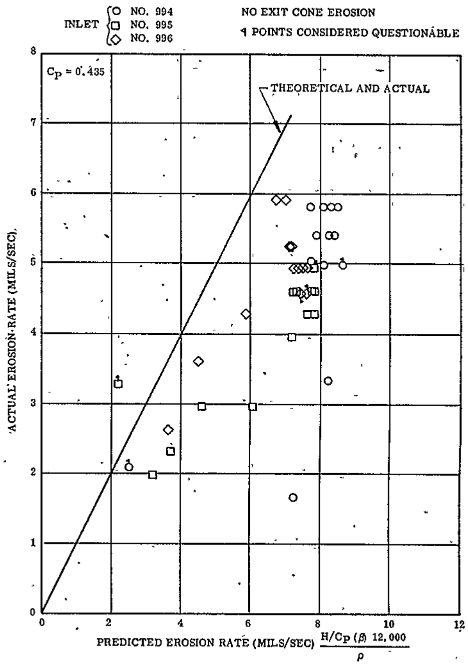


Figure 63. TU-379 Motor Erosion Performance, SP-8057 (Pluton H-1 Cloth Phenolic)

24535-6

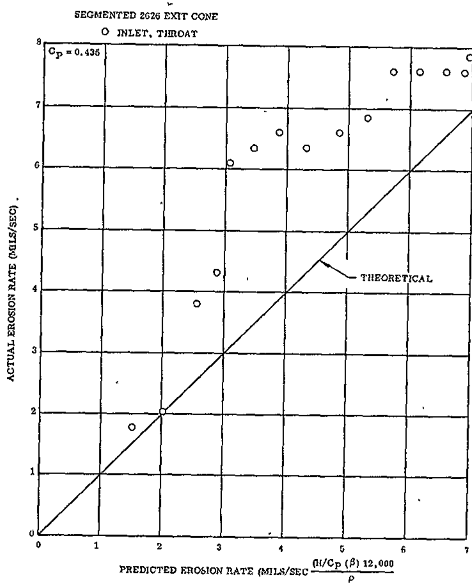


Figure 64. TU-622 Motor Erosion Performance, WB-8251 (Avceram C/S Cloth Phenolic)

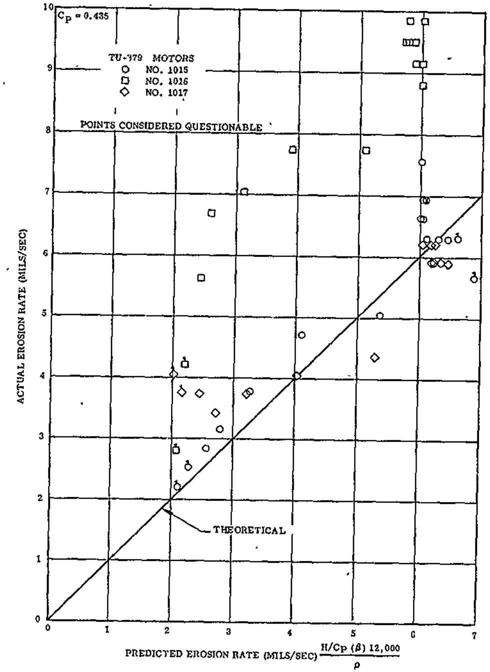


Figure 65 TU-379 Motor Erosion Performance, WB-8251 (Avceram C/S Cloth Phenolic)

24535-9

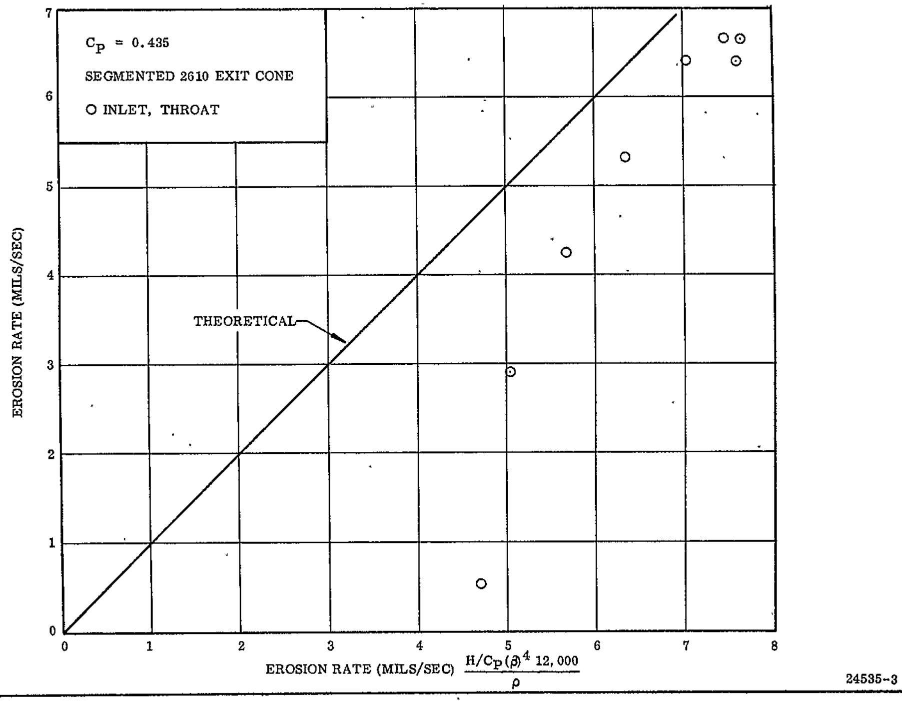


Figure 66. TU-622 Motor Erosion Performance , MXCS-198 (Avceram C/S Cloth Epoxy Novolac)

TABLE 26

TU-622 HIGH C/O RATIO MATERIAL PERFORMANCE

Material	Material Erosion Performance at Predicted Erosion Rate of 7.0 mils/sec		Material Cure Cycle		Reinforcement Resin Ratio	Reinforcement and Resin Type
	Theoretical Line (mils/sec)	Actual Line (mils/sec)	Pressure (psi)	Temperature (°F)		
LCCM-2610	7.00	3.40	1,000	315 ± 10	3/1	Graphite particle and phenolic
LCCM-4120	7.00	5.30	15	315 ± 10	3/1	Graphite particle and phenolic
4C-1686	7.00	3.00	225	350 ± 5	1.44/1	Carbon cloth and polyphenylene
SP-8057	7.00	7.00	225	315 ± 10	0.96/1	Carbon cloth and phenolic
WB-8251	7.00	7.5 Est.	225	315 ± 10	1.56/1	Carbon-silica cloth and phenolic
MXCS-198	7.00	6.4 Est.	15	315 ± 10	1.08/1	Carbon-silica cloth and epoxy novolac

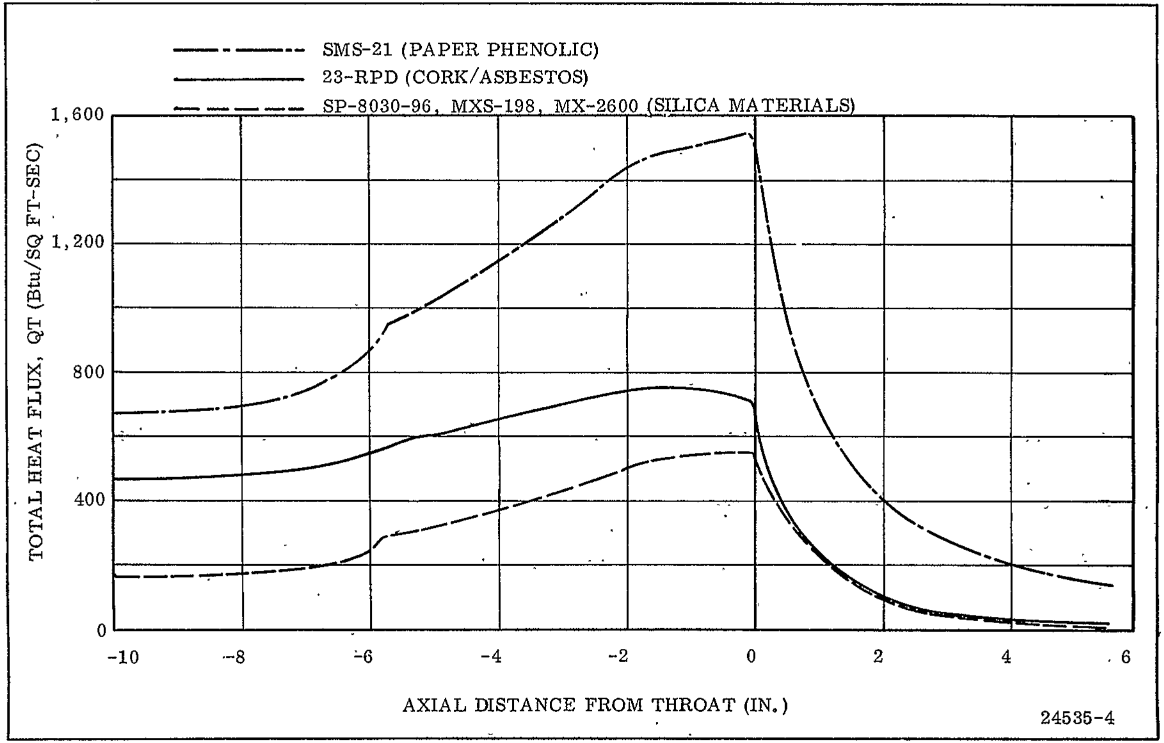


Figure 67. TU-622 Material Test Motor Total Heat Flux vs Axial Location

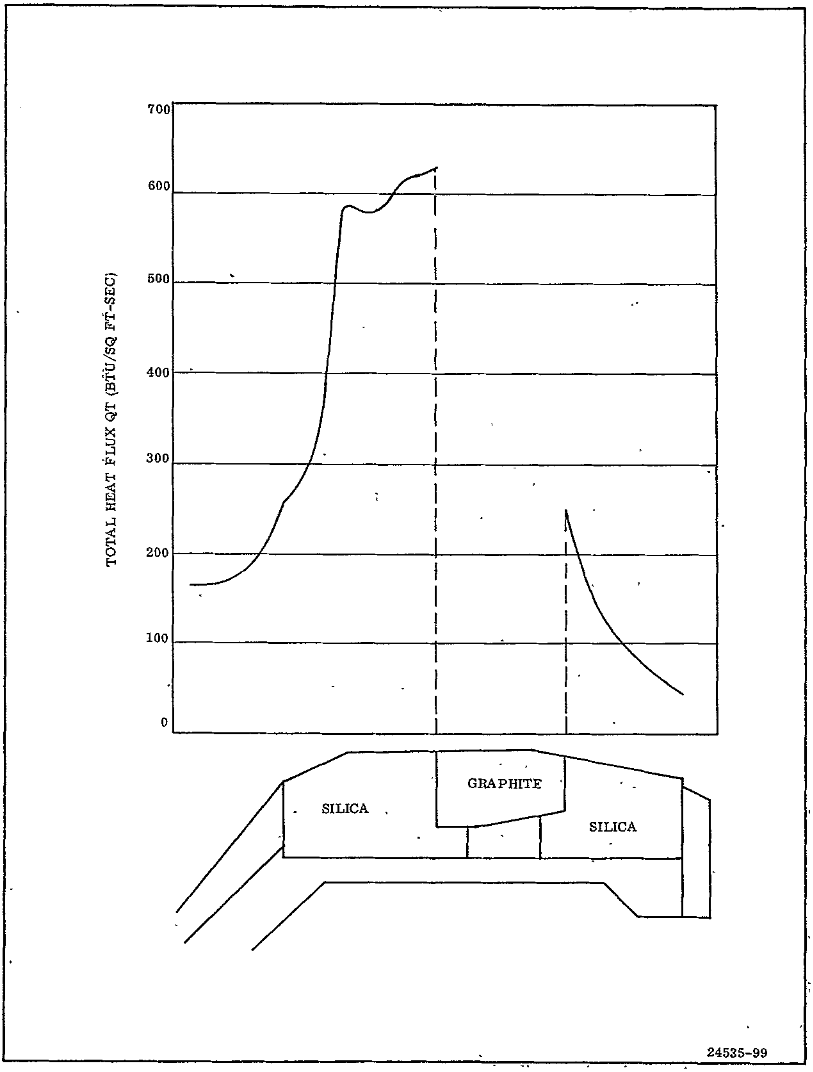


Figure 68. TU-379 Material Screening Motor Total Heat Flux vs Axial Location (Silica Material)

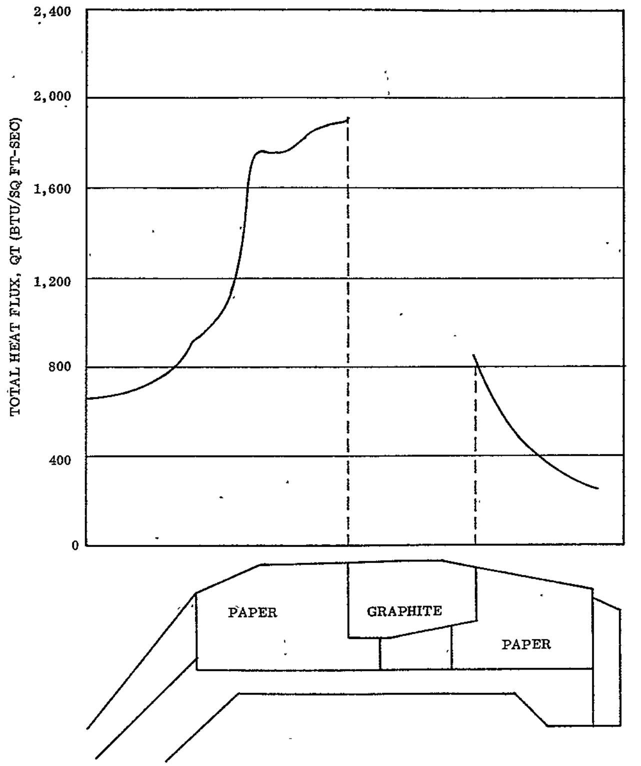


Figure 69. TU-379 Material Screening Motor, Total Heat Flux vs Axial Location (Paper Material)

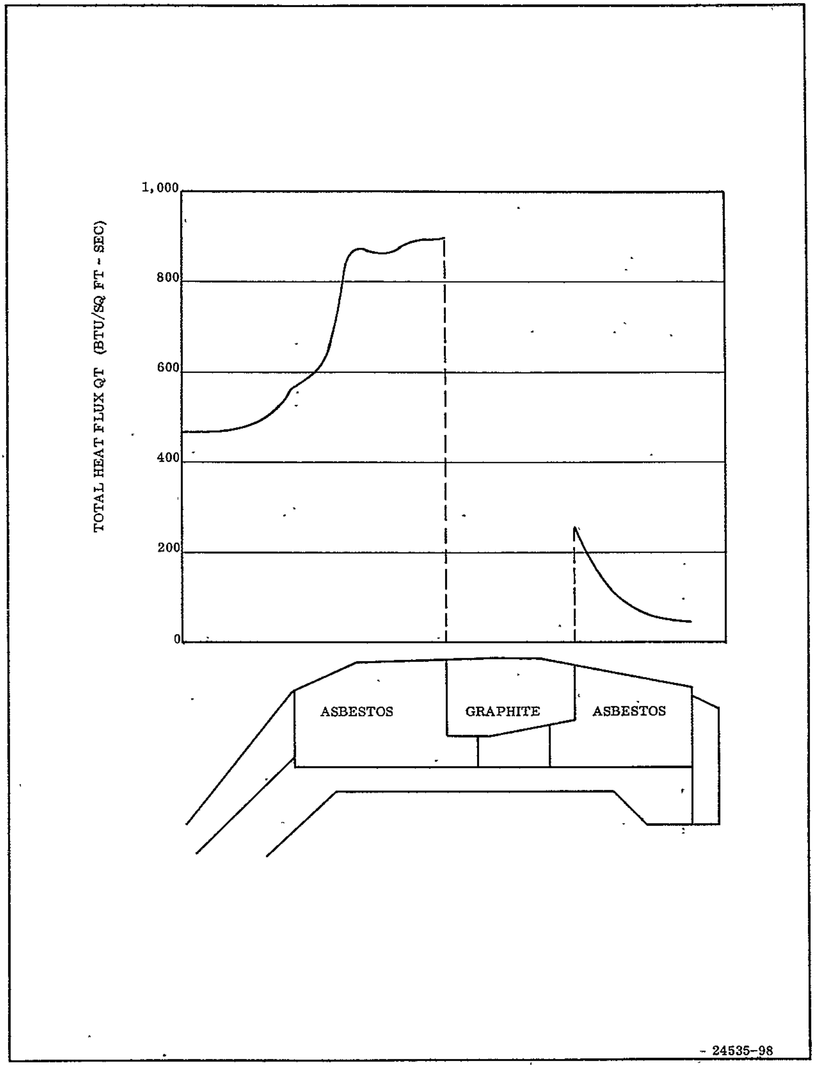


Figure 70. TU-379 Material Screening Motor Total Heat Flux vs Axial Location (Asbestos Material)

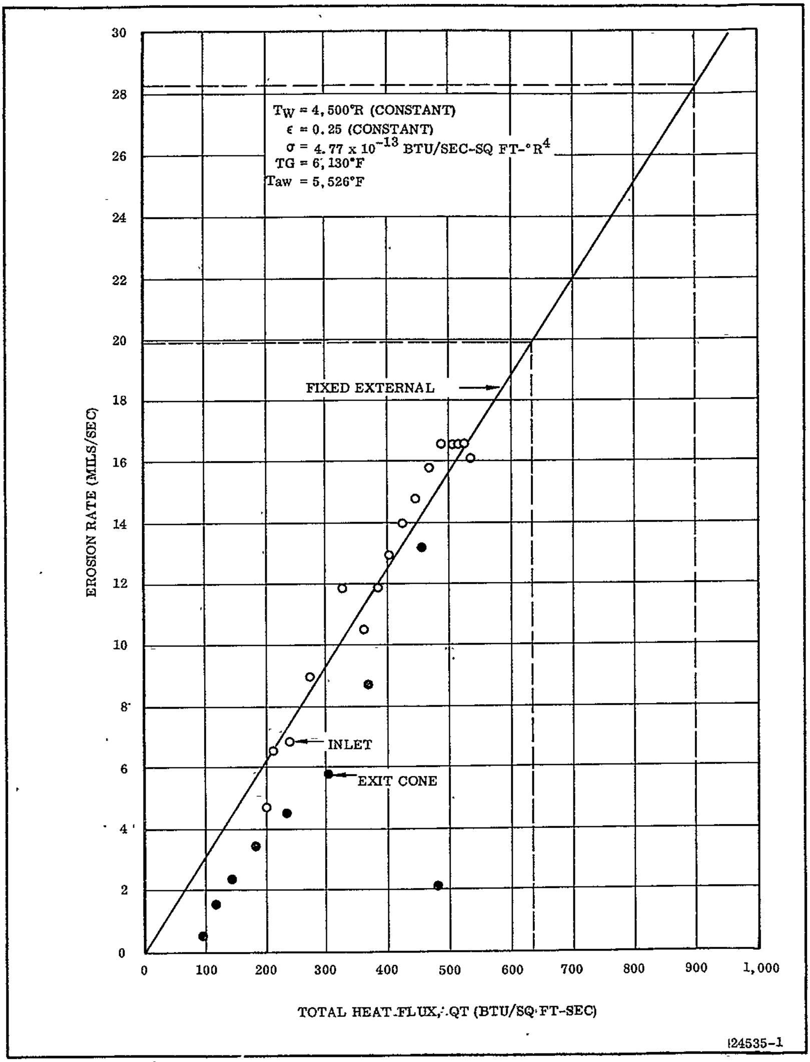


Figure 71. Erosion Performance Line for Low C/O Ratio Material (Silica SP-8030-96)

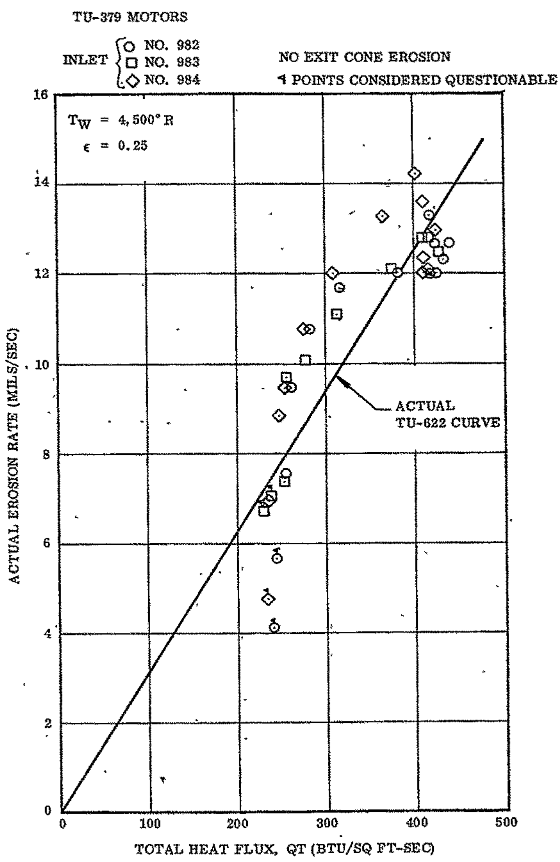


Figure 72. TU-379 Motor Erosion Performance, SP-8030-96 (Silica Cloth Phenolic)

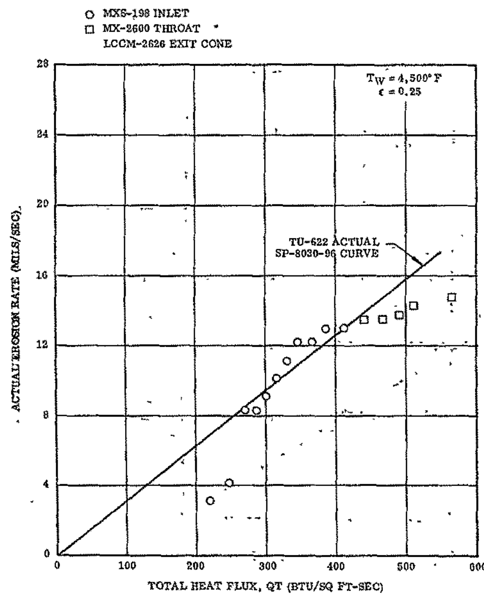


Figure 73. TU-622 Motor Erosion Performance, MXS-198 (Silica Cloth Epoxy Novolac) and MX-2600 (Silica Cloth Phenolic)

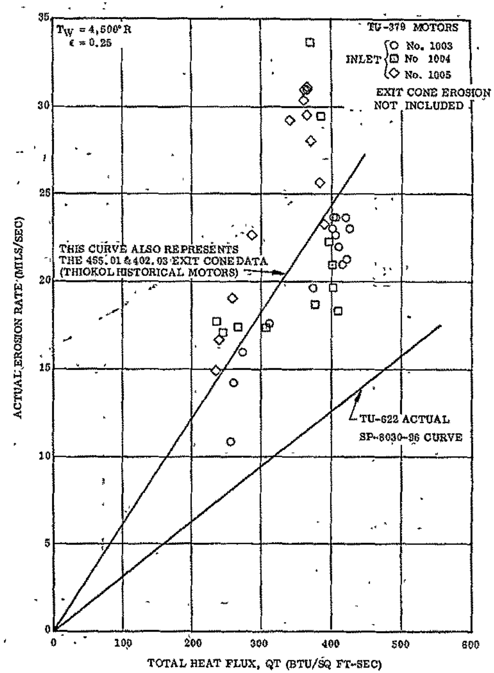


Figure 74. TU-379 Motor Erosion Performance, MXS-198 (Silica Cloth Epoxy Novolac)

24535-7

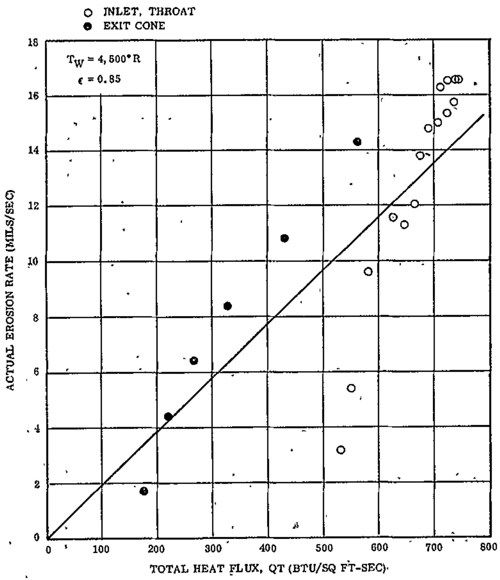


Figure 75. TU-622 Motor Erosion Performance, 23-RPD (Asbestos/Cork Phenolic)

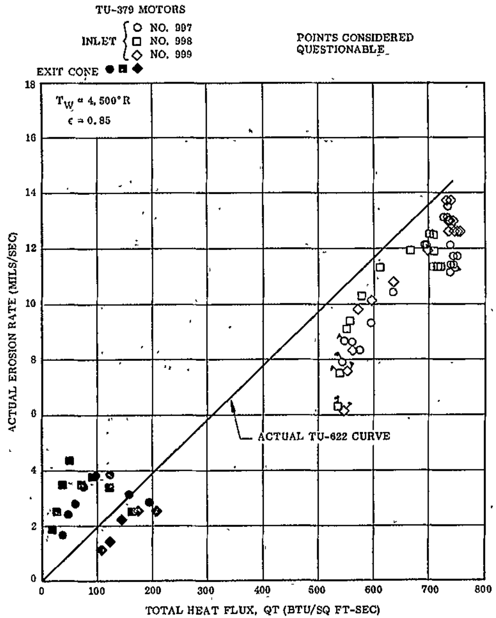


Figure 76. TU-379 Motor Erosion Performance, 23-RPD (Asbestos/Cork Phenolic)

44535-5

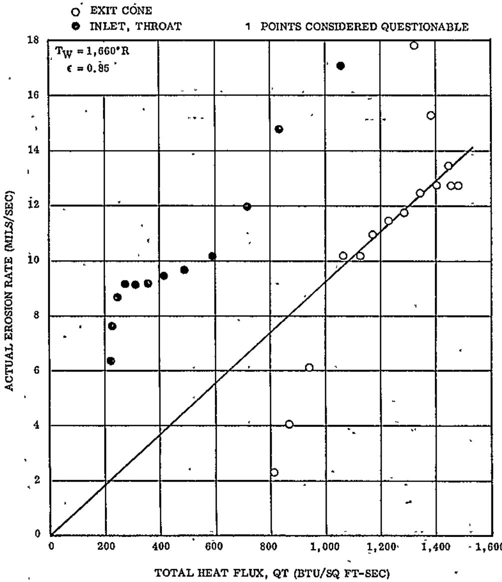


Figure 77. TU-622 Motor Erosion Performance, SMS-21 (Kraft Paper Phenolic)

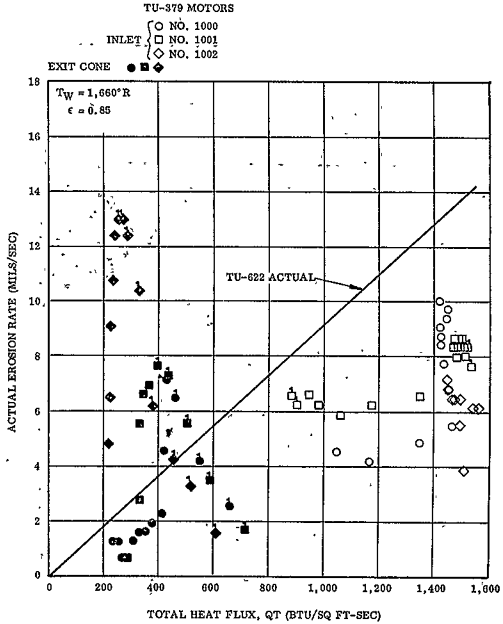


Figure 78. TU-379 Motor Erosion Performance, SMS-21 (Kraft Paper Phenolic)

24535-10

TABLE 27

TU-622 LOW C/O RATIO MATERIAL PERFORMANCE AT THE THROAT

Material	Erosion Performance: Total Heat Flux Q_T	Erosion Performance: Actual (mils/sec)	Reinforcement/ Resin Ratio	Reinforcement and Resin Type
SP-8030-96	525	16.5	2.57/1	Double thick silica cloth and phenolic
MXS-198	N/A	N/A	2.22/1	Silica cloth and epoxy novolac
MX-2600	565	17.0	N/A	Silica cloth and phenolic
23-RPD	725	14.0	1.70/1	Asbestos cork filled mat and phenolic
SMS-21	1,450	13.3	N/A	Paper mat and phenolic

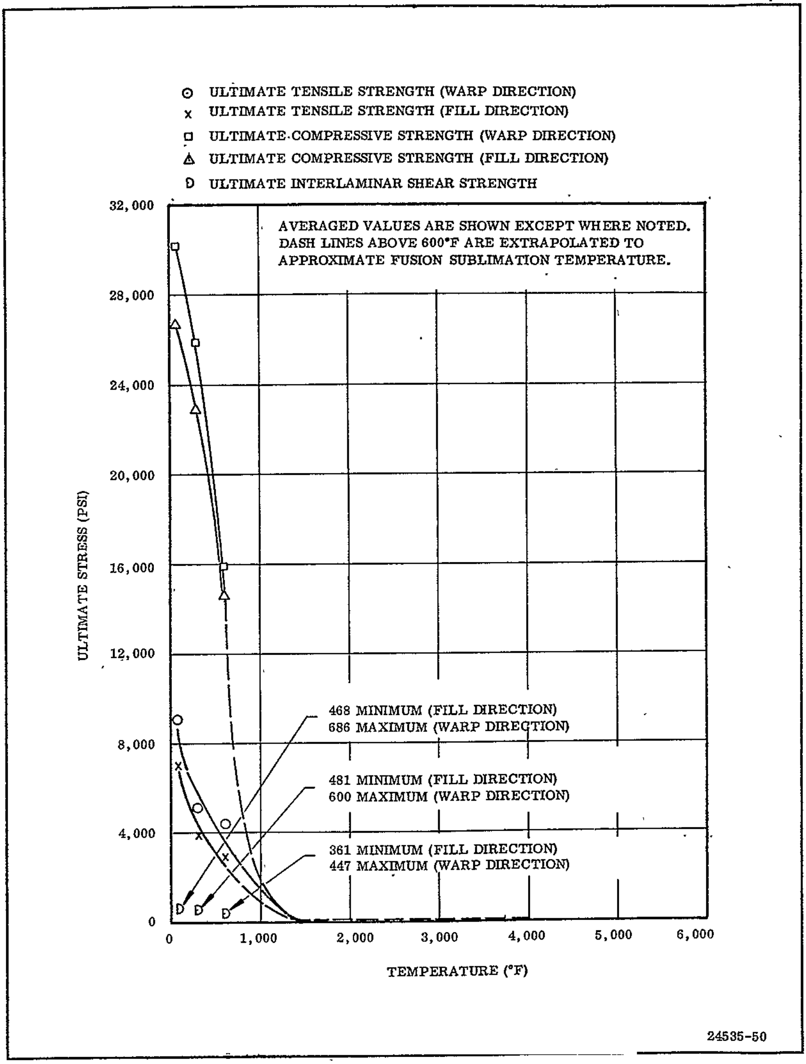


Figure 79. Mechanical Properties vs Temperature, WB-8251 (Avceram C/S Cloth Phenolic)

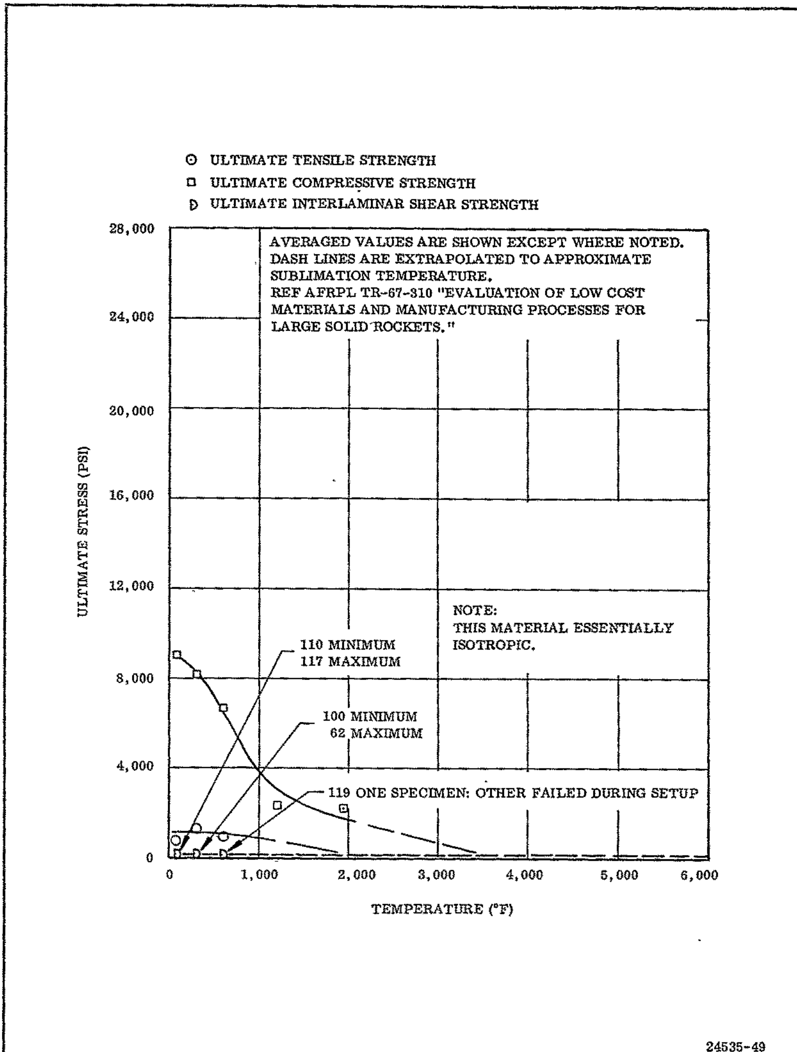


Figure 80. Mechanical Properties vs Temperature, LCCM-4120 (Graphite Particle Phenolic)

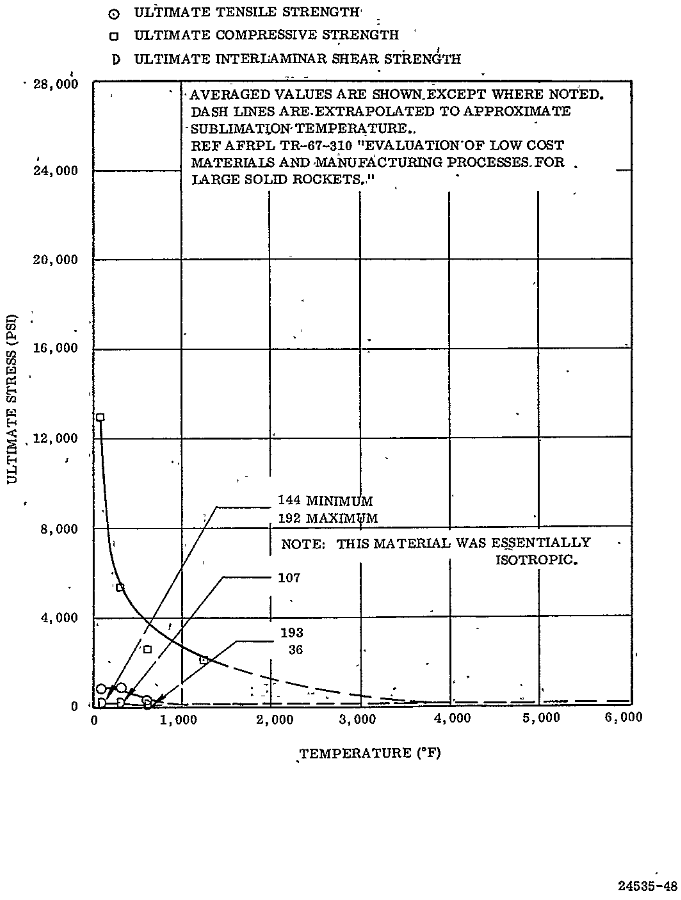


Figure 81. Mechanical Properties vs Temperature, LCCM-2610 (Graphite Particle Phenolic)

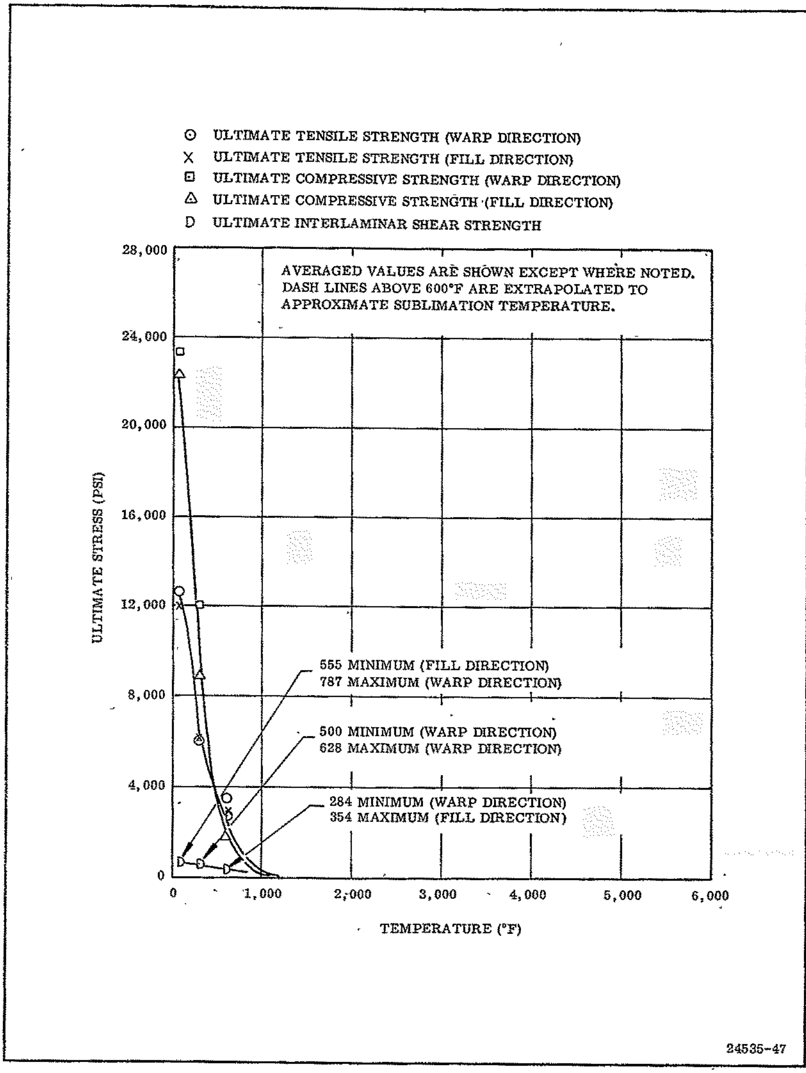


Figure 82. Mechanical Properties vs Temperature, SMS-21 (Kraft Paper Phenolic)

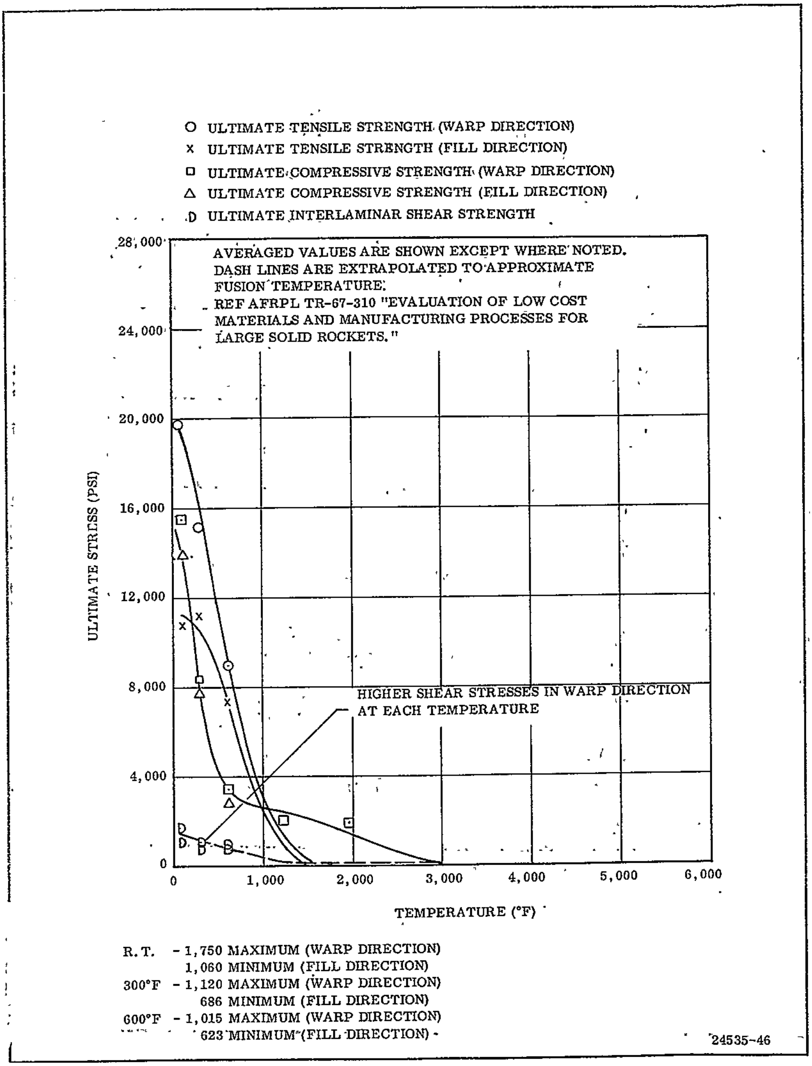


Figure 83. Mechanical Properties vs Temperature, 23-RPD (Asbestos/Cork Phenolic)

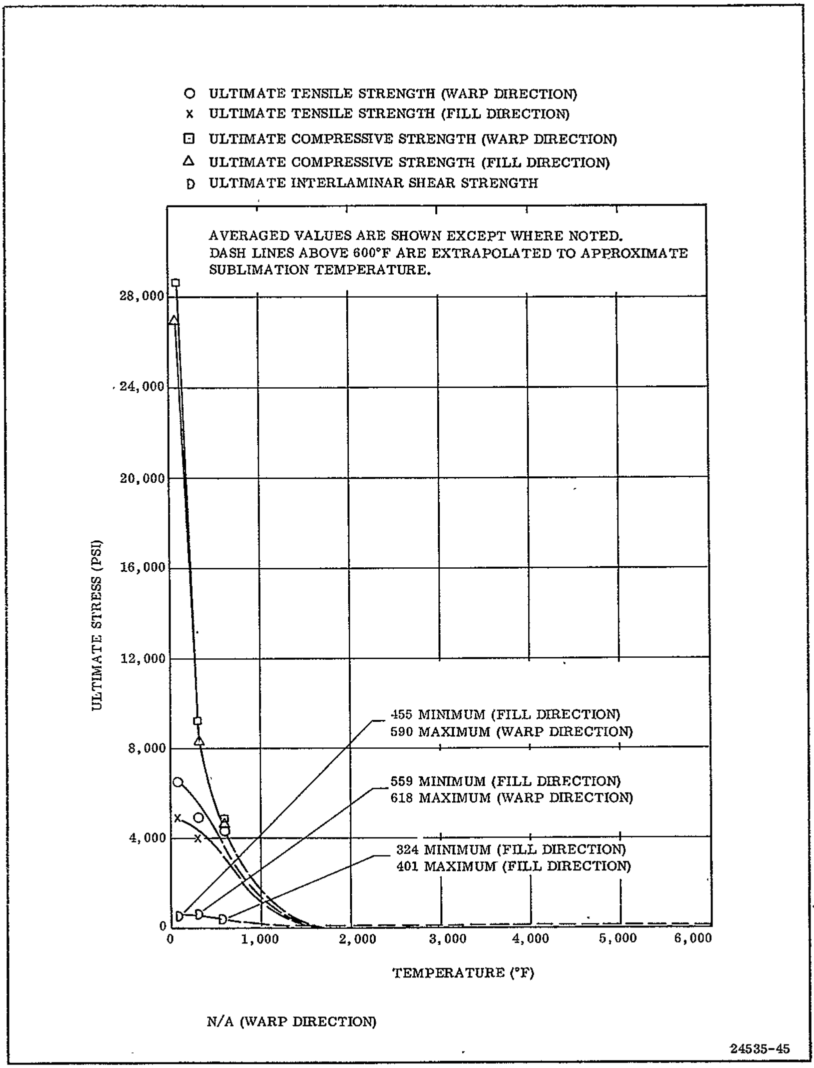


Figure 84. Mechanical Properties vs Temperature, SP-8057 (Pluton H-1 Cloth Phenolic)

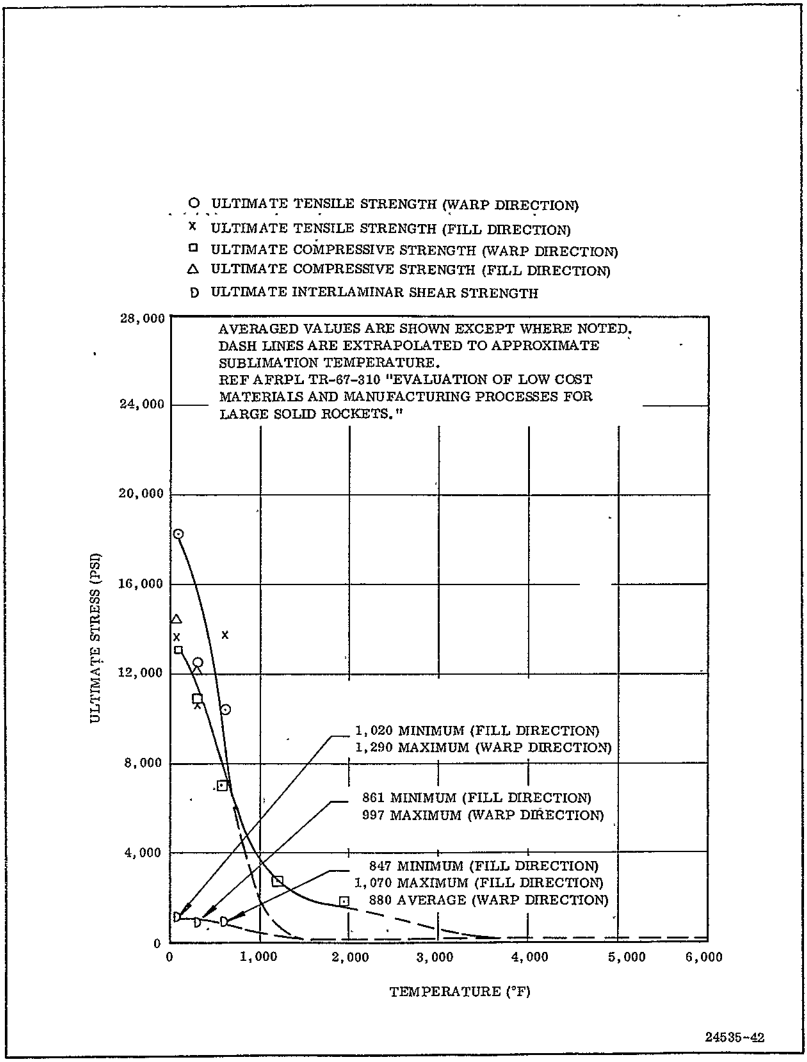


Figure 85. Mechanical Properties vs Temperature, 4C-1686 (Carbon Cloth Polyphenylene)

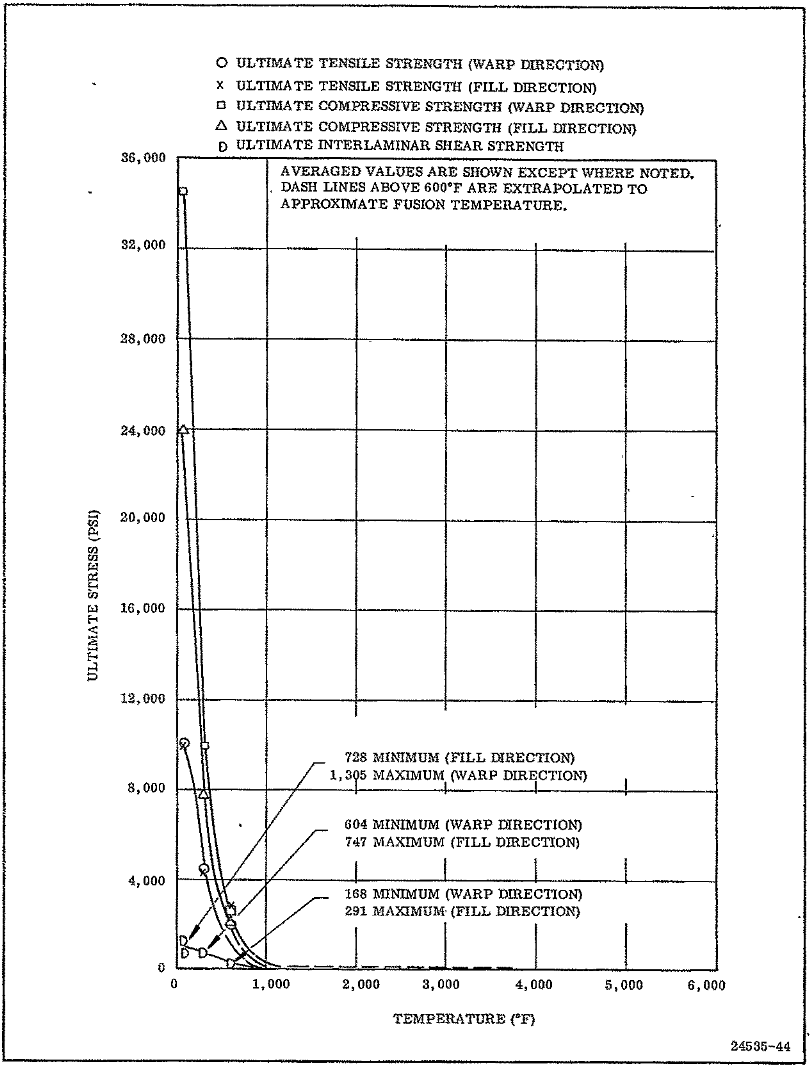


Figure 86. Mechanical Properties vs Temperature, MXS-198 (Silica Cloth Epoxy Novolac)

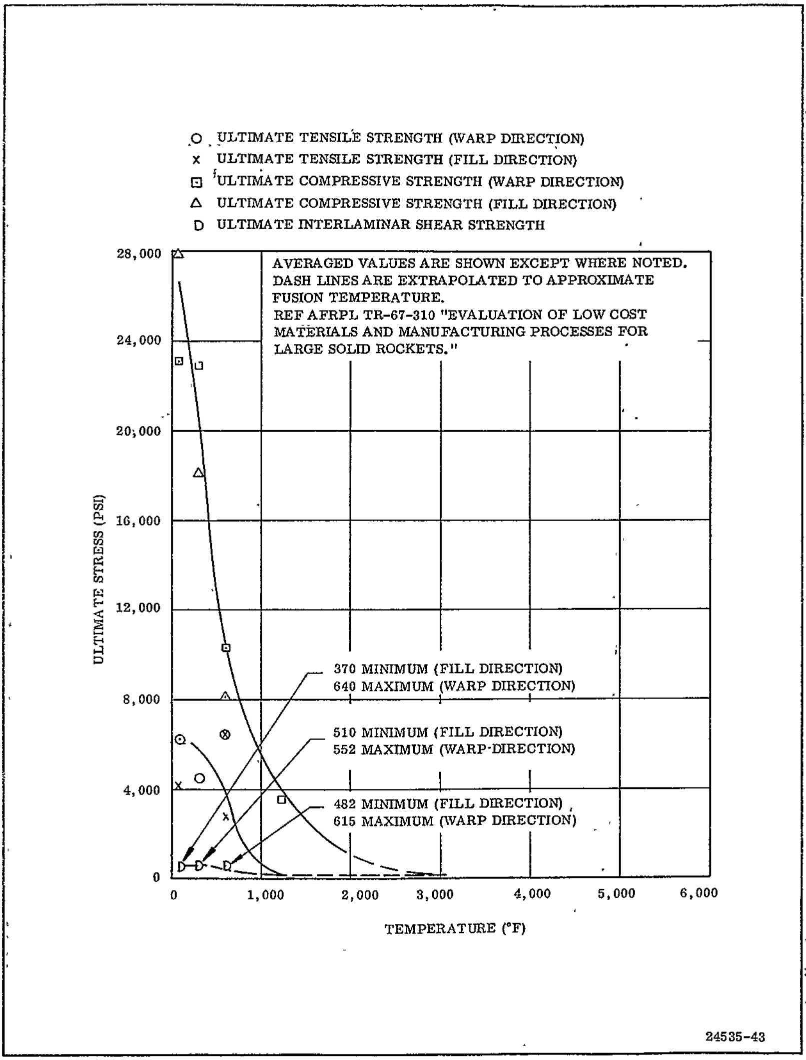


Figure 87. Mechanical Properties vs Temperature, SP-8030-96 (Silica Cloth Phenolic)

TABLE 28

HIGH TEMPERATURE COMPRESSION TESTS

Material	Test Temperature (°F)	Ultimate Compression (psi)
SP-8030-96 (Heavyweight silica fabric phenolic)	1,930-1,950	2,120
	1,930-1,950	2,920
	1,930-1,950	3,120
		Avg 2,720
	1,250	3,175
	1,225	4,490
	1,200	2,870
		Avg 3,510
23-RPD (Cork filled asbestos phenolic)	1,950	2,590
	1,950	2,105
		1,005
		Avg 1,900
	1,250	1,855
	1,250	2,075
	1,225	1,975
		Avg 1,970
4C-1686 (Carbon fabric polyphenylene)	1,950	1,575
	1,950	1,875
	1,950	1,735
		Avg 1,730
	1,200	2,770
	1,200	2,350
	1,200	2,885
		Avg 2,670
LCCM-2626 (Graphite particle phenolic)	1,930-1,950	3,620
	1,930-1,950	3,600
	1,930-1,950	3,520
		Avg 3,580
	1,200	1,180
	1,225	3,600
	1,250	1,380
		Avg 2,050
LCCM-4120 (Graphite particle phenolic)	1,900-1,950	1,910
	1,900-1,950	2,550
		Avg 2,230
	1,220	2,350
	1,200	2,375
		Avg 2,360
KF-418 (Canvas cloth phenolic)	1,950	Burned out
	1,250	260 Prior to burnout

TABLE 29

THERMAL CONDUCTIVITY OF NOZZLE MATERIALS

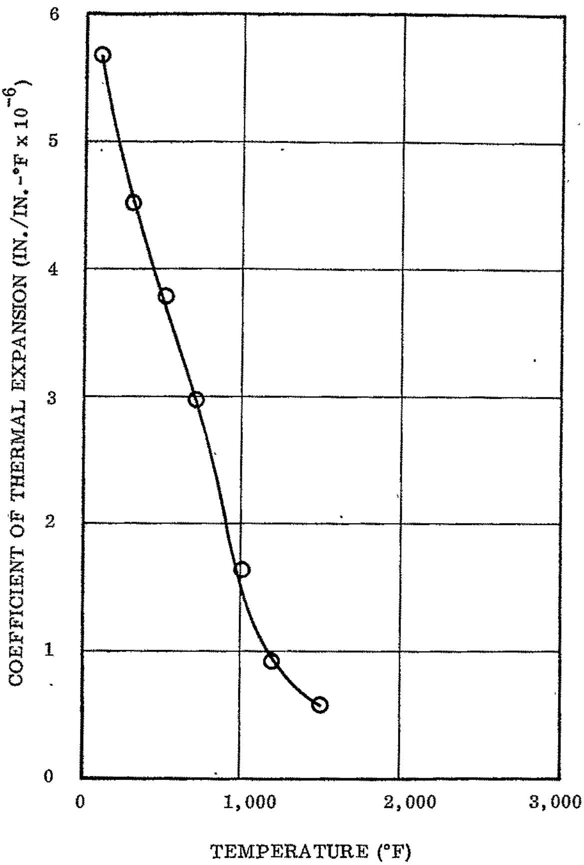
Material		Thermal Conductivity (Btu/in.)/(sq ft/sec/°F) 32°F	207°F
23-RPD		2.39×10^{-4}	2.05×10^{-4}
		2.18×10^{-4}	2.05×10^{-4}
	Avg	2.29×10^{-4}	2.05×10^{-4}
4C-1686		4.96×10^{-4}	4.44×10^{-4}
		5.18×10^{-4}	4.30×10^{-4}
	Avg	5.07×10^{-4}	4.37×10^{-4}
SP-8030-96		3.60×10^{-4}	2.31×10^{-4}
		3.31×10^{-4}	2.46×10^{-4}
	Avg	3.46×10^{-4}	2.38×10^{-4}
SP-8057		4.51×10^{-4}	4.24×10^{-4}
		4.61×10^{-4}	4.37×10^{-4}
	Avg	4.56×10^{-4}	4.32×10^{-4}
LCCM-2626		10.62×10^{-4}	11.41×10^{-4}
		10.70×10^{-4}	12.23×10^{-4}
	Avg	10.66×10^{-4}	11.82×10^{-4}

TABLE 30

SPECIFIC HEAT OF NOZZLE MATERIALS

Material		Specific Heat (Btu/lb/°F)					
		32°F	144°F	200°F	300°F	600°F*	900°F*
23-RPD		0.383	0.296	0.294	0.316	0.351	0.358
		0.385	0.290	0.298	0.320	0.345	0.368
	Avg	0.384	0.293	0.296	0.318	0.348	0.363
4C-1686		0.303	0.253	0.244	0.274	0.325	0.376
		0.306	0.260	0.244	0.273	0.325	0.377
	Avg	0.304	0.256	0.244	0.274	0.325	0.377
SP-8030-96		0.319	0.222	0.223	0.248	0.279	0.303
		0.311	0.218	0.217	0.248	0.277	0.307
	Avg	0.315	0.220	0.220	0.248	0.278	0.305
SP-8057		0.326	0.300	0.297	0.336	0.354	0.388
		0.329	0.306	0.298	0.340	0.358	0.364
	Avg	0.328	0.303	0.296	0.338	0.356	0.376
LCCM-2626		0.300	0.215	0.235	0.259	0.317	0.352
		0.292	0.214	0.234	0.273	0.319	0.357
	Avg	0.296	0.215	0.235	0.266	0.318	0.355

*Samples exhibited significant weight loss at 600° and 900°F. The sample weight used to calculate the specific heat was the weight after heating to these temperatures.



24535-65

Figure 88. Carbon Polyphenylene 4C-1686, Coefficient of Thermal Expansion vs Temperature (with Lamina Laboratory Virgin Material)

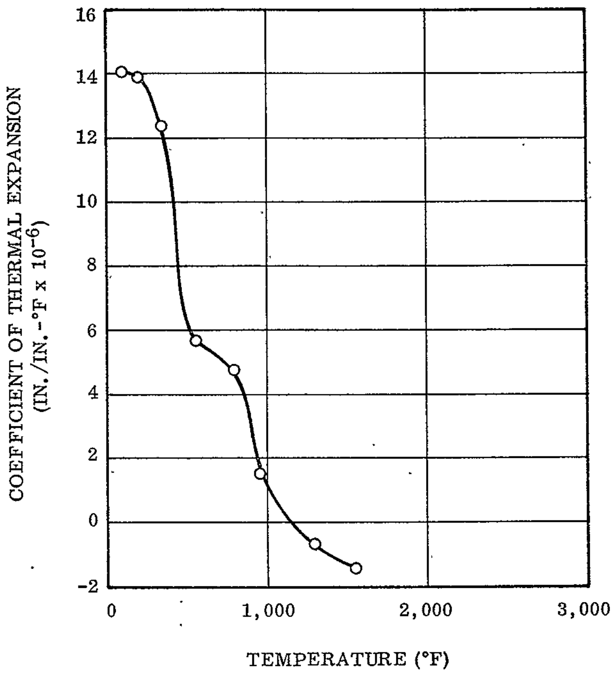


Figure 89. Carbon Phenolic SP-8057, Coefficient of Thermal Expansion vs Temperature (with Lamina Laboratory Virgin Material)

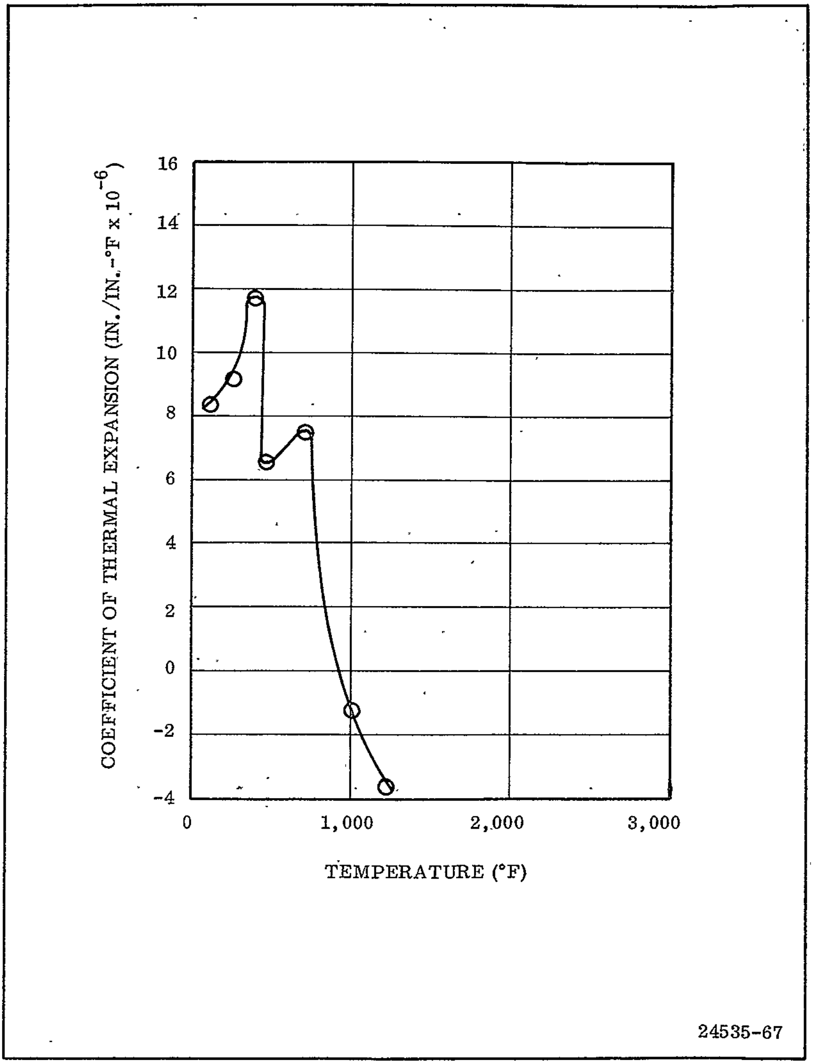


Figure 90. Graphite Particle Phenolic LCCM-2626, Coefficient of Thermal Expansion vs Temperature (with Lamina Laboratory Virgin Material)

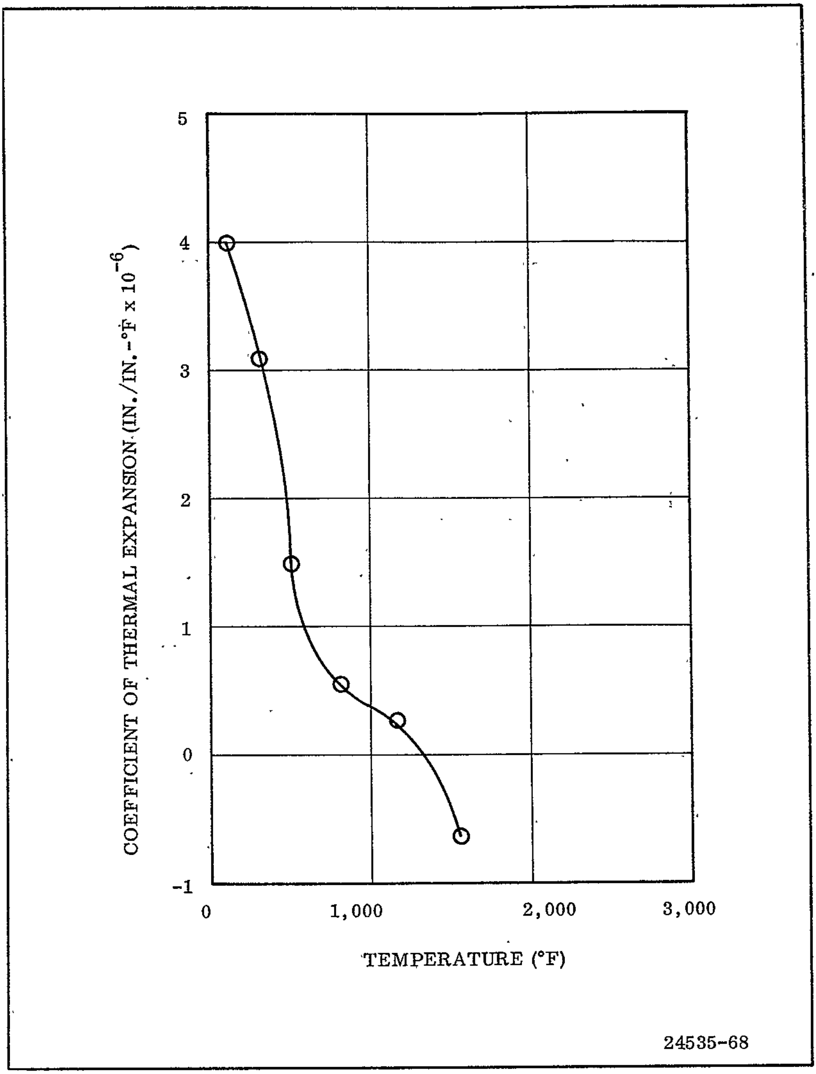


Figure 91. Silica Phenolic SP-8030-96, Coefficient of Thermal Expansion vs Temperature (with Lamina Laboratory Virgin Material)

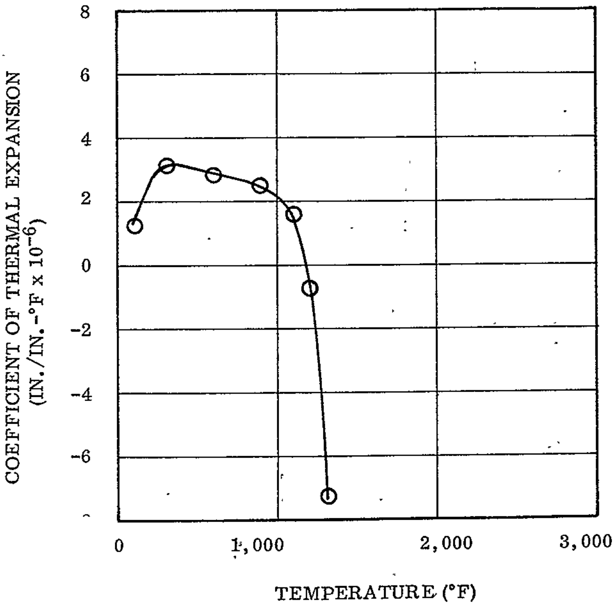


Figure. 92. Asbestos Phenolic 23-RPD, Coefficient of Thermal Expansion vs Temperature (with Lamina Laboratory Virgin Material)

TABLE 31

LIST OF MATERIAL CANDIDATES FOR THE SUBSCALE NOZZLE TASK

Number	Family	Material	Vendor	General Description	Specific Gravity	Raw Material Cost ($/lb)
1	LCCM	LCCM-2626	Thiokol	Graphite particle - phenolic molding compound	1.8	0.75
2		LCCM-4120	Thiokol	Graphite particle - phenolic casting compound	1.5	0.75
3	Carbon reinforced	SP-8057	Armour	Pluton-H fabric - EC-201 phenolic	1.4	15.00
4		4C1686	Coast	GS-CC2 carbon fabric-polyphenylene	1.3	20.60
5		SP-8050[a]	Armour	CCA-1 carbon-EC-201 phenolic	1.44	16.50
6		WB-8217[a]	Cordo	Carbon fabric - WB-2233 phenolic	1.42	20.97
7		MX-4926[a]	Fiberite	Carbon fabric - phenolic	1.40	19.00
8	Avceram reinforced	WB-8251	Cordo	Avceram C/S - WB-2233 phenolic	1.5	12.97
9		MXCS-198[b]	Fiberite	Avceram C/S - epoxy novolac	--	--
10	Silica reinforced	SP-8030-96	Armour	C-100-96 silica fabric-EC-201 phenolic resin	1.6	4.90
11		MXS-198	Fiberite	C-100-96 silica fabric-epoxy novolac	1.5	6.10
12	Asbestos reinforced	23-RPD	Raybestos-Manhattan	Cork filled asbestos phenolic	1.5	4.25
13		MXA-6012[a]	Fiberite	Crocidolite asbestos	1.61	1.85
14	Cotton or paper reinforcement	KF-418[a]	Fiberite	Canvas duct-SC-1008 phenolic	1.35	1.50
15		FM-5272[a]	US Polymeric	Kraft crepe paper-USP 100 phenolic	1.34	2.00
16		SMS-21	Thiokol	Paper phenolic	1.3	1.20

[a]Materials preselected for subscale evaluation by NASA and Thiokol Chemical Corporation.

[b]Materials not tested

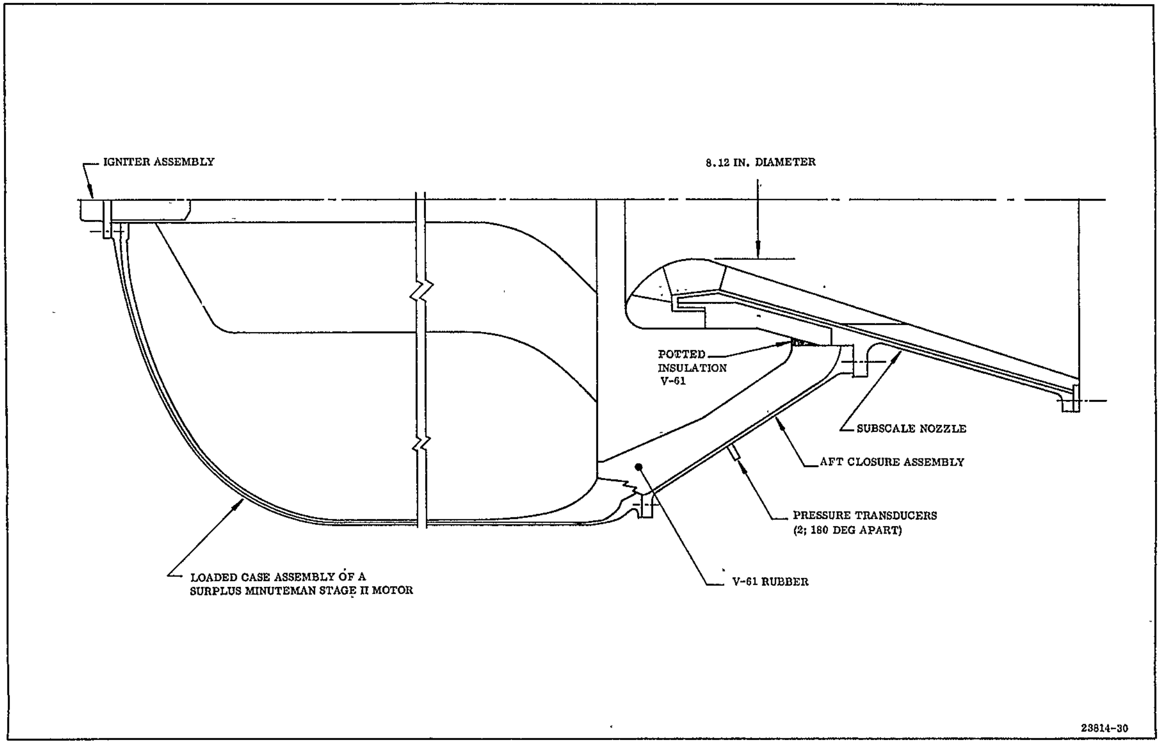


Figure 93. Subscale Nozzle Test Motor Assembly

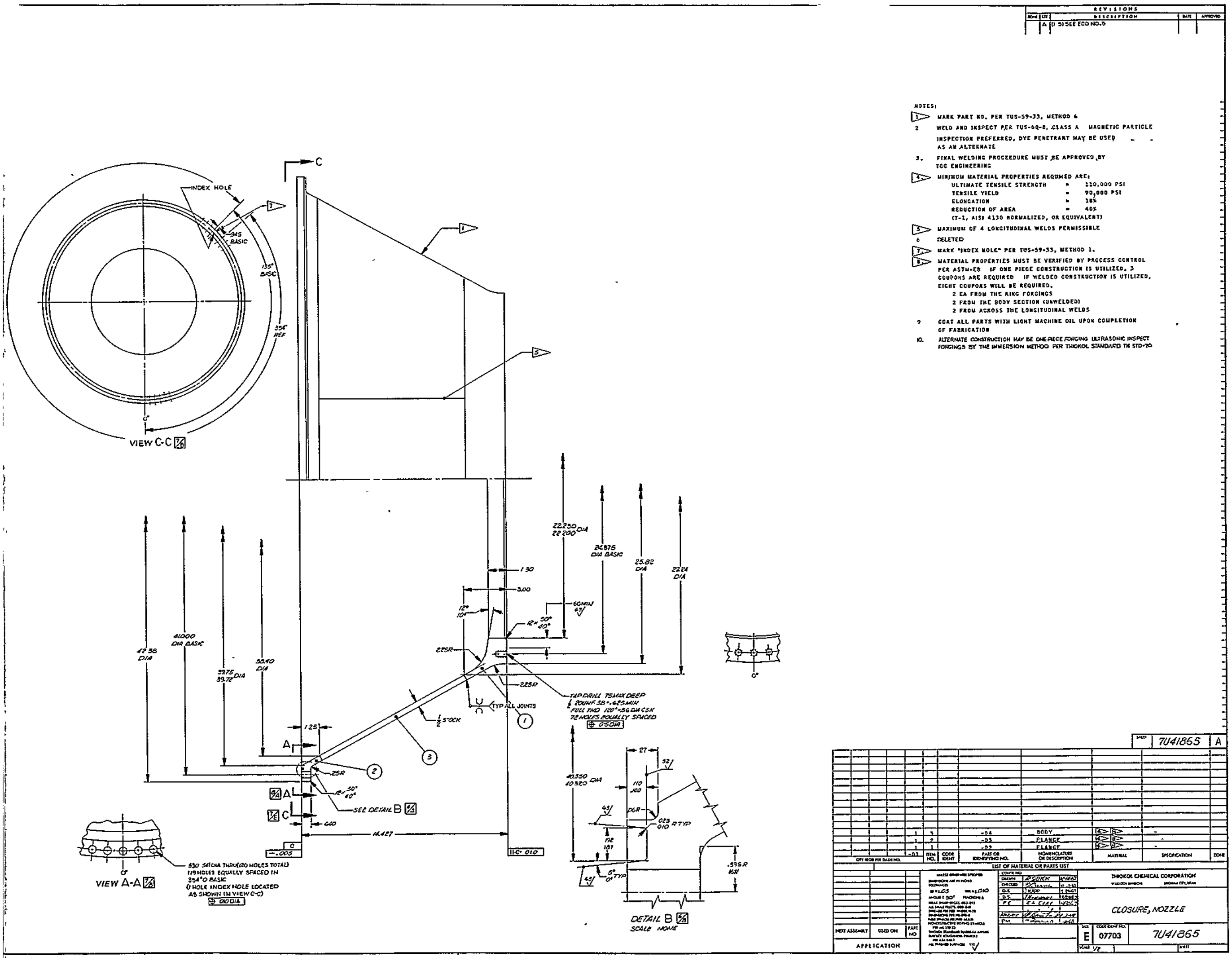
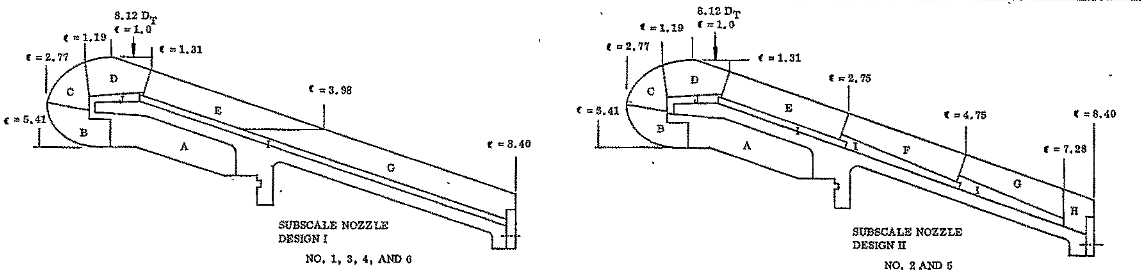


Figure 94. Subscale Aft Closure

TABLE 32

SUBSCALE NOZZLE MATERIALS TEST LOCATION



TESTED MATERIALS

NOZZLE NO.	NOZZLE DESIGN	A	B	C	D	E	F	G	H	I	J
1	I	FM-5272 PAPER PHENOLIC	WB-8217 CARBON PHENOLIC	WB-8217 CARBON PHENOLIC	MX-4926 CARBON PHENOLIC	SP-8050 CARBON PHENOLIC	—	KF-418 CANVAS PHENOLIC	—	MXA-6012 ASBESTOS PHENOLIC	MXA-6012 ASBESTOS PHENOLIC
2	II	MXA-6012 ASBESTOS PHENOLIC	4C-1686 CARBON POLY-PHENYLENE	4C-1686 CARBON POLY-PHENYLENE	LCCM-2626 GRAPHITE PARTICLE PHENOLIC	LCCM-2626X GRAPHITE PARTICLE PHENOLIC SEGMENTED	LCCM-2626X GRAPHITE PARTICLE PHENOLIC SEGMENTED	LCCM-2626X GRAPHITE PARTICLE PHENOLIC SEGMENTED	FM-5063 CARBON PHENOLIC	1581 GLASS PHENOLIC	23-RPD ASBESTOS CORK PHENOLIC
3	I	23-RPD ASBESTOS CORK PHENOLIC	SP-8057 CARBON PHENOLIC	SP-8057 CARBON PHENOLIC	SP-8050 CARBON PHENOLIC	SP-8057 CARBON PHENOLIC	—	SP-8030-96 SILICA PHENOLIC	—	23-RPD ASBESTOS CORK PHENOLIC	FM-5272 PAPER PHENOLIC
4	I	KF-418 CANVAS PHENOLIC	KF-418 CANVAS PHENOLIC	SP-8030-96 SILICA PHENOLIC	SP-8030-96 SILICA PHENOLIC	23-RPD ASBESTOS CORK PHENOLIC	—	MXS-198 SILICA EPOXY NOVOLAC	—	KF-418 CANVAS PHENOLIC	SP-8030-96 SILICA PHENOLIC
5	II	KF-418 CANVAS PHENOLIC	SP-8030-96 SILICA PHENOLIC	LCCM-2626 GRAPHITE PARTICLE PHENOLIC	LCCM-2626 GRAPHITE PARTICLE PHENOLIC SEGMENTED	LCCM-2626X GRAPHITE PARTICLE PHENOLIC	LCCM-4120 GRAPHITE PARTICLE PHENOLIC	LCCM-4120 GRAPHITE PARTICLE PHENOLIC	KF-418 CANVAS PHENOLIC	1581 GLASS PHENOLIC	23-RPD ASBESTOS CORK PHENOLIC
6	I	SP-8030-96 SILICA PHENOLIC	FM-5272 PAPER PHENOLIC	SP-8030-96 SILICA PHENOLIC	SP-8057 CARBON PHENOLIC	KF-418 CANVAS PHENOLIC	—	FM-5272 PAPER PHENOLIC	—	FM-5272 PAPER PHENOLIC	KF-418 CANVAS PHENOLIC

24535-63

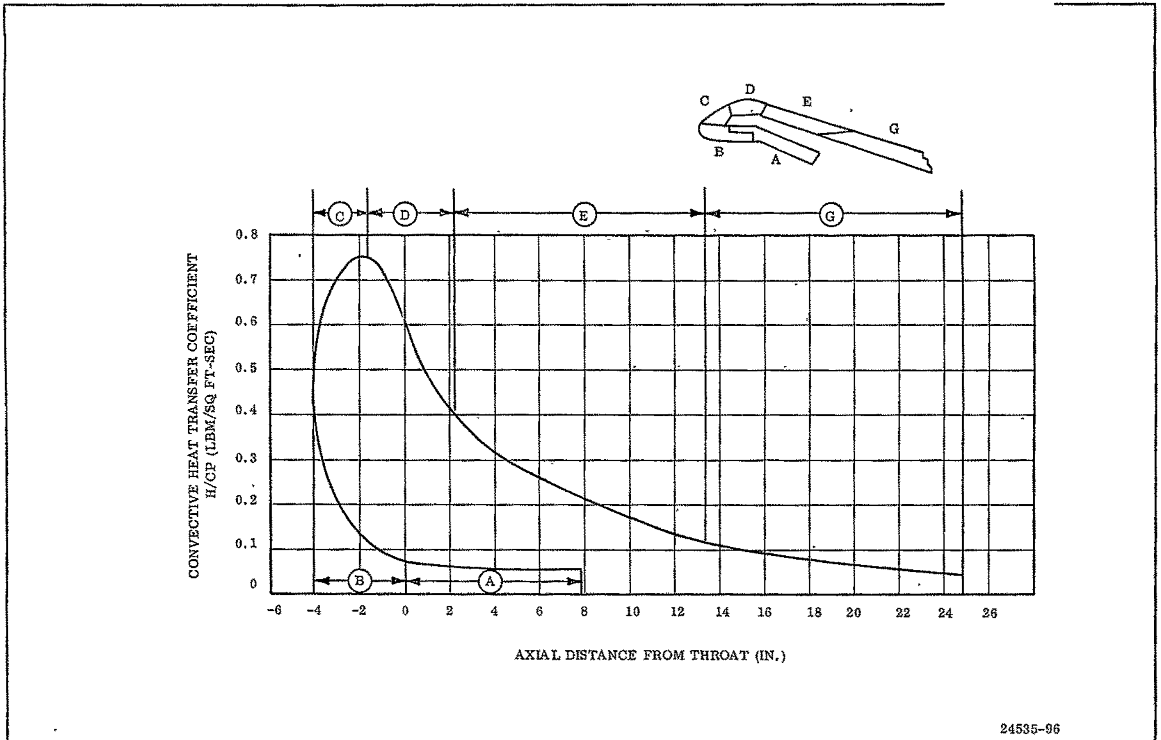


Figure 96. Subscale Nozzle Convective Heat Transfer Coefficient (Carbonaceous Material)

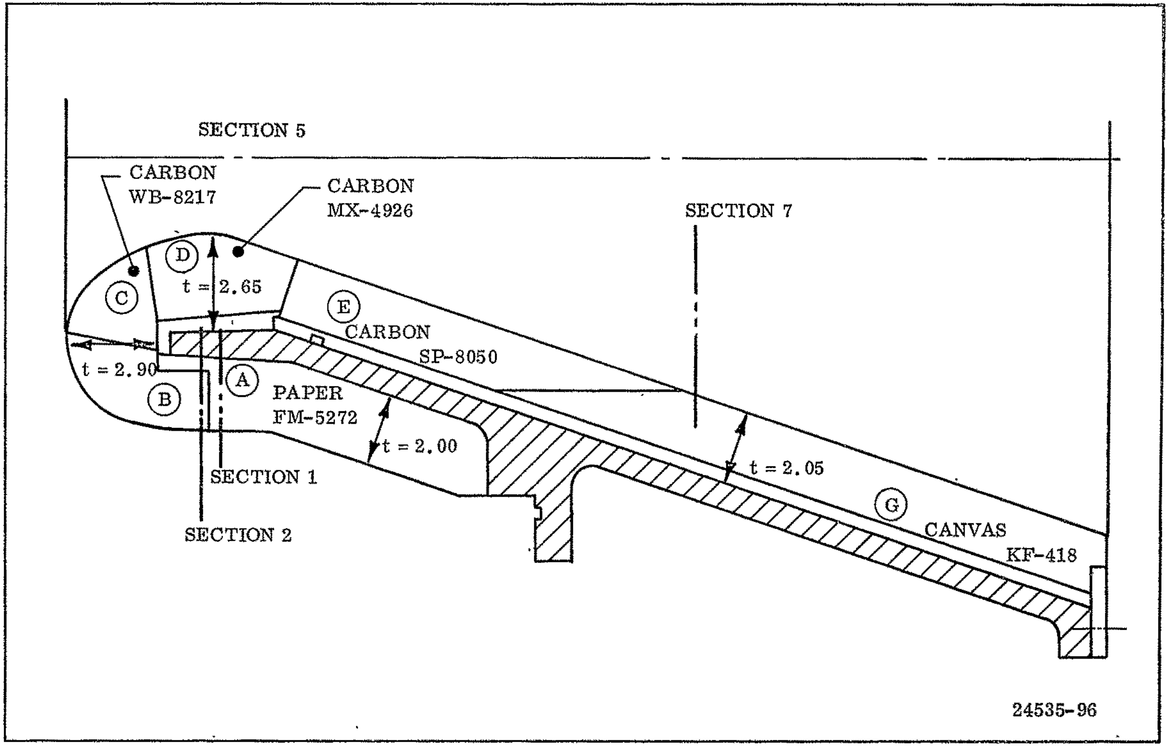


Figure 97. Subscale Nozzle No. 1 Thermal Gradient Planes

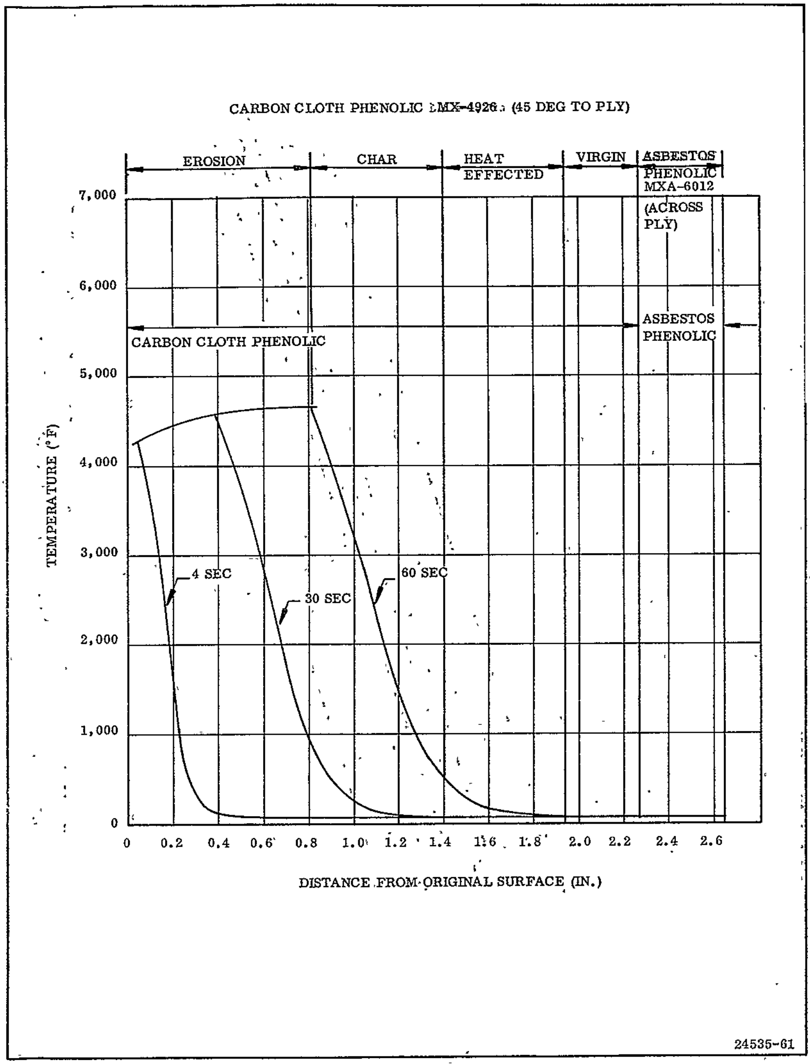


Figure 98. Nozzle No. 1 Thermal Gradient, Throat Section No. 5

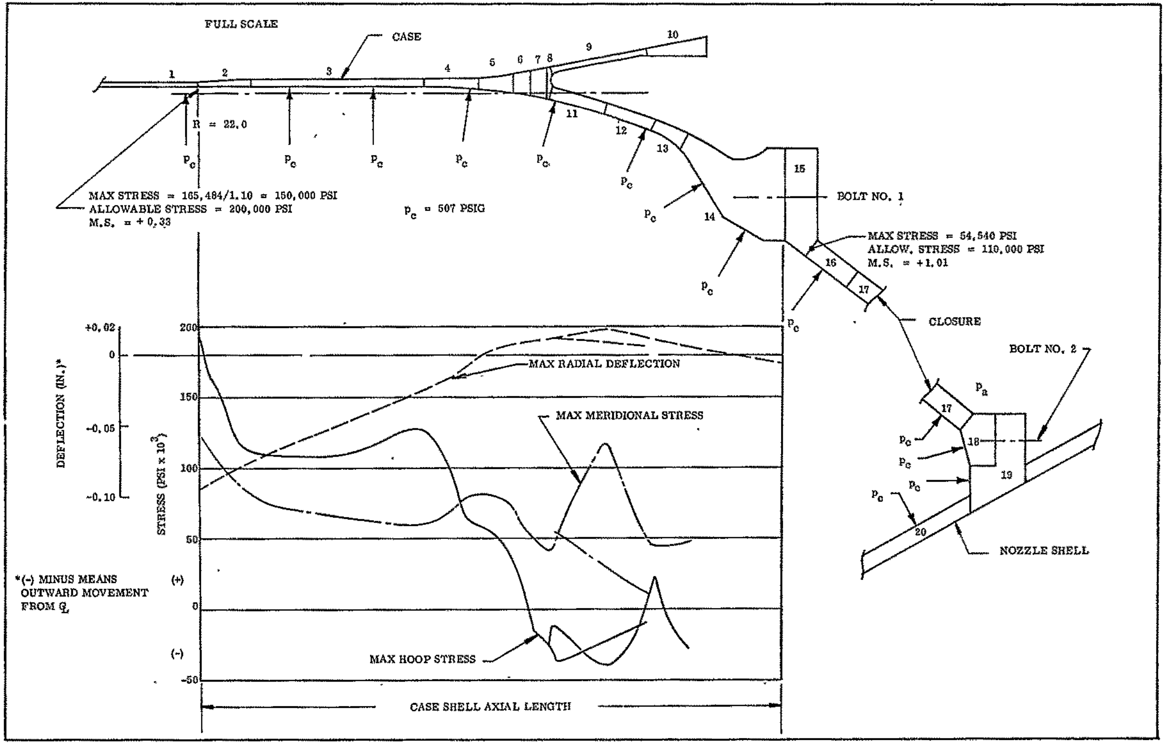


Figure 99. Stage II Minuteman Structural Analysis

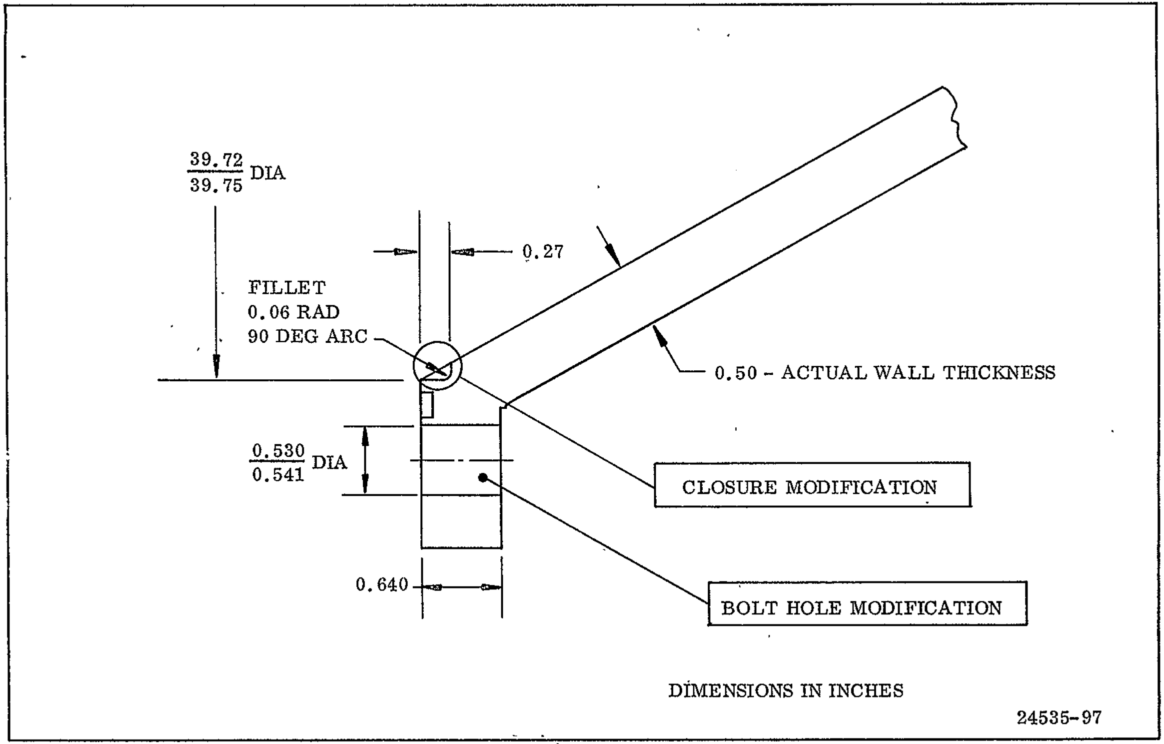


Figure 100. Nozzle Closure Modification

TABLE 33

NOZZLE NO. 1 COMPONENT FABRICATION

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly SP-8050 KF-418 MXA-6012	Tape wrap halfway up cone mandrel with 6 in. SP-8050 tape, switch to 6 in. KF-418 tape, and complete wrapping of cone. Autoclave cure. Overwrap full length of cone with 1 1/2 in. MXA-6012 tape. Autoclave cure.	Cure No. 1. Apply vacuum and 225 psi positive pressure. Cure 1 hr at 200°F, 1 hr at 250°F, 6 hr at 300°F. Cool to 150°F under pressure. Cure No. 2. Apply vacuum and stage 3 hr at 180°F. Apply 225 psi 1/2 hr at 200°F. Cure 1/2 hr at 225°F, 1 hr at 250°F, 1 hr at 275°F, 4 hr at 300°F. Cool to 150°F under pressure.
Throat Billet MX-4926	Cut 900 "coolie hat" plies. Install in compression tool, debulking as required. Install male punch and press cure.	Apply 225 psi (calculated). Cure 2 hr at 200°F, 2 hr at 250°F, 6 hr at 320°F. Cool to 150°F under pressure.
Throat Backup MXA-6012	Tape wrap cylindrical mandrel with 5 in. MXA-6012 tape. Autoclave cure.	Apply vacuum and stage 3 hr at 180°F; apply 225 psi. Cure 1/2 hr at 200°F, 1/2 hr at 225°F, 1 hr at 250°F, 4 hr at 300°F. Cool to 150°F under pressure.
Inlet Ring Billet WB-8217	Cut 130 deg ply patterns. Install in mold, butting ply ends together. Debulk as required. Install male punch and press cure.	Apply 225 psi (calculated). Cure 1 hr at 200°F, 1 hr at 250°F, 3 hr at 300°F. Cool to 150°F under pressure.
Nose Ring Billet WB-8217	Tape wrap 5 in. WB-8217 on cylindrical mandrel, debulking as required. Autoclave cure.	Apply vacuum and 225 psi positive pressure. Cure 1 hr at 200°F, 1 hr at 250°F, 6 hr at 300°F. Cool to 150°F under pressure.
Backside Insulation Billet FM-5272	Tape wrap full length of cone mandrel with 6 in. FM-5272 tape. Overwrap full length with 3 in. FM-5272 tape. Autoclave cure.	Apply vacuum and 225 psi; stage 3 hr at 180°F. Cure 1-1/2 hr at 250°F, 6 hr at 310°F. Remove from mandrel while hot (180°-200°F).

TABLE 34

NOZZLE NO. 2 COMPONENT FABRICATION

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly LCCM-2626 Glass-Phenolic Tape	Compression mold billets of LCCM-2626. Machine into segments. Bond segments together on mandrel and overwrap with glass phenolic tape. Autoclave cure. Machine tiers and assemble together.	Cure No. 1 - LCCM-2626. Load tool with calculated quantity of molding compound. Apply 200 tons pressure. Cure 10 hr at 325° F. Cure No. 2 - Overwrap. Apply vacuum and 225 psi autoclave pressure. Cure 2 hr at 200° F, 2 hr at 250° F, 4 hr at 310° F. Cool under vacuum and pressure to 150° F.
Throat Billet LCCM-2626	Add molding compound to compression tool, install male punch and press cure.	Apply 1,000 psi. Cure 6 hr at 325° F.
Throat Backup Billet 23-RPD	Tape wrap cylindrical mandrel with 5 in. 23-RPD tape. Autoclave cure.	Apply vacuum and stage 2 hr at 180° F; apply 225 psi. Cure 2 hr at 180° F, 2 hr at 240° F, 2 hr at 270° F, 3 hr at 310° F. Cool to 150° F under vacuum and pressure.
Inlet Ring Billet 4C-1686	Cut 130 deg ply patterns Install in mold, butting ply ends together. Install male punch and press cure.	Apply 225 psi. Cure 2 hr at 180° F, 2 hr at 210° F, 2 hr at 240° F, 2 hr at 270° F, 2 hr at 300° F, 5 hr at 350° F. Cool to 160° F under pressure.
Nose Ring Billet 4C-1686	Tape wrap cylindrical mandrel with 5 in. tape. Autoclave cure.	Apply 225 psi. Cure 2 hr at 180° F, 2 hr at 210° F, 2 hr at 240° F, 2 hr at 270° F, 2 hr at 300° F, 4 hr at 350° F. Cool under vacuum and pressure to 160° F.
Backside Liner Billet MXA-6012	Make two full-length wraps of conical mandrel with 5 in. tape. Autoclave cure.	Apply vacuum, stage 3 hr at 180° F, apply 225 psi. Cure 2 hr at 200° F, 2 hr at 225° F, 2 hr at 250° F, 2 hr at 275° F, 6 hr at 310° F. Cool under vacuum and pressure to 150° F.

TABLE 35

NOZZLE NO. 3 COMPONENT FABRICATION

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly SP-8057 Forward SP-8030-96 Aft 23-RPD Overwrap	Wrap forward portion of conical mandrel with 6 in. SP-8057 tape. Wrap aft portion with 6 in. SP-8030-96 tape. Autoclave cure. Overwrap cone with 2-1/2 in. 23-RPD tape. Autoclave cure.	Cure No. 1. Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 200°F, 3 hr at 225°F, 3 hr at 250°F, 3 hr at 275°F, 6 hr 310°F. Cool under pressure to 150°F at a rate not to exceed 25°F per 1/2 hr. Cure No. 2. Apply vacuum and stage 3 hr at 180°F. Apply 225 psi. Cure 3 hr at 250°F, 6 hr at 310°F. Cool as in No. 1.
Throat Insert Billet SP-8050	Hand layup "coolie hat" method. Cut required number of plies. Install in compression tool with 45 deg starter ring in bottom. Debulk. Install male punch and press cure.	Apply 225 psi (calculated). Cure 2 hr at 200°F, 2 hr at 250°F, 6 hr at 320°F. Cool to 150°F under pressure.
Throat Backup Billet FM-5272	Tape wrap on cylindrical mandrel with 5 in. tape. Install vacuum bag and autoclave cure.	Apply vacuum and 225 psi. Cure 1 hr at 180°F, 2 hr at 250°F, 4 hr at 310°F. Cool to 200°F and remove from mandrel while hot.
Inlet Ring Billet SP-8057	Cut required number of plies. Hand layup in mold. Debulk as required. Install male punch and press cure.	Apply 225 psi (calculated). Cure 2 hr at 180°F, 2 hr at 250°F, 2 hr at 275°F, 4 hr at 310°F. Cool to 160°F or lower under pressure.
Backside Liner Billet 23-RPD	Tape wrap full length of conical mandrel with 5 in. 23-RPD tape, stage. Overwrap full length of cone with 5 in. 23-RPD tape. Autoclave cure.	Stage 1st wrap under vacuum for 3 hr at 180°F. After 2nd wrap (overwrap) stage as for nose ring billet below. Apply 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, 6 hr at 310°F. Cool to 150°F or lower under pressure.
Nose Ring Billet SP-8057	Tape wrap 5 in. SP-8057 on cylindrical mandrel, debulking as required. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 210°F, 2 hr at 240°F, 2 hr at 270°F, 4 hr at 300°F. Cool to 160°F or lower under pressure.

TABLE 36

NOZZLE NO. 4 COMPONENT FABRICATION SUMMARY

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly 23-RPD Forward MXS-198 Aft KF-418 Overwrap	Wrap forward portion of conical mandrel with 6 in. 23-RPD tape. Cure No. 1. Wrap aft portion with 6 in. MXS-198 tape. Cure No. 2. Overwrap entire cone with 2-1/2 in. KF-418 tape. Cure No. 3.	Cure No. 1. Stage 3 hr at 180°F under vacuum. Apply 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, 6 hr at 310°F. Cool to 160°F or lower. Cure No. 2. Vacuum bag only. Cure 2 hr at 180°F, 2 hr at 200°F, 3 hr at 250°F, 3 hr at 275°F, 9 hr at 310°F. Cool to 180°F at 25°F per hour. Cure No. 3. Apply vacuum and 225 psi. Cure 2 hr at 200° F, 2 hr at 250° F, 2 hr at 275° F, 6 hr at 310° F. Cool to 150° F at 25° F per hr.
Throat Billet SP-8030-96	Hand layup "coolie hat" method. Cut required number of plies. Install in compression tool with 45 deg starter ring in bottom. Debulk, install male punch, and press cure.	Apply 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, 2 hr at 275°F, 6 hr at 310°F. Cool to 160°F at 30°F per hr under pressure.
Throat Backup SP-8030-96	Tape wrap on cylindrical mandrel with 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 1 hr at 180°F, 2 hr at 200°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F at 30°F per hour.
Inlet Billet SP-8030-96	Cut required number of plies. Hand layup in mold. Debulk. Install male punch and press cure.	Apply 225 psi. Cure 2 hr at 180°F, 2 hr at 250°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F at 30°F per hour.
Nose Billet KF-418	Tape wrap 5 in. tape on cylindrical mandrel. Debulk as required. Cure in autoclave.	Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 225°F, 2 hr at 250°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F.
Backside Liner KF-418	Tape wrap over conical mandrel with 5 in. tape. Stage. Overwrap staged part with 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 225°F, 2 hr at 250°F, 3 hr at 275°F, 6 hr at 310°F. Cool under pressure to 160°F.

TABLE 37

NOZZLE NO. 5 COMPONENT FABRICATION SUMMARY

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly LCCM-2626 LCCM-4120 KF-418 Glass Phenolic	Compression mold billets of LCCM-2626 and LCCM-4120. Machine OD. Install on mandrel and overwrap with glass phenolic tape. Autoclave cure. Machine tiers and assemble. Tape wrap KF-418 tape on mandrel. Autoclave cure. Machine and install into steel nozzle shell.	Cure No. 1 - LCCM-2626. Load compression tool with material. Cure 24 hr at 325°F and 850 psi. Cure No. 2 - LCCM-4120. Cast material into mold. Vacuum bag. Cure 24 hr at 325°F and 1 atmosphere pressure. Cure No. 3 - Overwrap. Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 225°F, 3 hr at 250°F, 3 hr at 275°F, 6 hr at 310°F. Cool under pressure to 160°F. Cure No. 4 - KF-418 Ring. Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 225°F, 2 hr at 250°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F.
Throat Assembly LCCM-2626 23-RPD	Compression mold LCCM-2626 billet. Machine into four segments. Install segments on mandrel and overwrap with 23-RPD. Autoclave cure.	Cure No. 1 - LCCM-2626. Load compression tool with material. Cure 12 hr at 325°F and 1,000 psi. Cure No. 2 - Overwrap. Apply vacuum bag and 225 psi. Cure 1 hr at 180°F and 3 hr at 300°F. Cool under pressure to 200°F.
Inlet Ring Billet LCCM-2626	Compression mold LCCM-2626.	Load tool with material and apply 1,000 psi. Cure 2 hr at 250°F, 2 hr at 275°F, 8 hr at 310°F.
Nose Ring Billet SP-8030-96	Tape wrap cylindrical mandrel with 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 225°F, 3 hr at 250°F, 3 hr at 275°F, 6 hr at 310°F. Cool under vacuum and pressure to 150°F.
Backside Liner Billet KF-418	Make two full length wraps of conical mandrel with 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 200°F, 3 hr at 225°F, 3 hr at 250°F, 3 hr at 275°F, 6 hr at 310°F. Cool to 150°F.

TABLE 38

NOZZLE NO. 6 COMPONENT FABRICATION SUMMARY

Component and Materials	Fabrication Method	Cure
Exit Cone Assembly KF-418, Forward FM-5272, Aft FM-5272, Over	Tape wrap forward portion. Tape wrap aft portion. Autoclave cure. Machine OD. Overwrap entire cone. Autoclave cure. Machine and install.	Cure No. 1. Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 225°F, 2 hr at 250°F, 2 hr at 275°F, 8 hr at 310°F. Cool under pressure to 180°F. Cure No. 2 - Overwrap. Apply vacuum and 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, 2 hr at 275°F, 6 hr at 310°F. Cool under pressure to 150°F.
Throat Billet SP-8057	Hand layup "coolie hat" method. Cut required number of plies. Install in compression tool with 45 deg starter ring. Debulk. Install male punch and press cure.	Apply 225 psi. Cure 2 hr at 200°F, 2 hr at 250°F, 2 hr at 275°F, 6 hr at 310°F. Cool under pressure to 160°F.
Throat Backup KF-418	Tape wrap on cylindrical mandrel with 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 1 hr at 180°F, 2 hr at 200°F, 2 hr at 240°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F.
Inlet Ring Billet SP-8030-96	Cut required number of plies. Hand layup in mold. Debulk. Install male punch and press cure.	Apply 225 psi. Cure 2 hr at 180°F, 2 hr at 250°F, 2 hr at 275°F, 4 hr at 310°F. Cool under pressure to 160°F at a rate of 30°F/hr.
Nose Ring Billet FM-5272	Tape wrap 5 in. tape on cylindrical mandrel. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 180°F, 2 hr at 225°F, 2 hr at 275°F, 6 hr at 310°F. Cool under pressure to 180°F. Remove part immediately while at 180°F.
Backside Liner Billet SP-8030-96	Tape wrap over conical mandrel with 5 in. tape. Stage. Overwrap with additional 5 in. tape. Autoclave cure.	Apply vacuum and 225 psi. Cure 2 hr at 180° F, 2 hr at 200° F, 3 hr at 225° F, 3 hr at 250° F, 3 hr at 275° F, 6 hr at 310° F. Cool under pressure to 150° F.

TABLE 39

COMPONENT RADIOGRAPHIC INSPECTION RESULTS

Nozzle No.	Component	Discrepancy	Disposition
1	Exit cone	None	
	Throat	Several delaminations	Removed during final machining
	Throat backup	Folds and resin rich areas, 1 metallic inclusion	Use as is
	Inlet	None	
	Nose	Numerous small delaminations, 2 inclusions	Removed during final machining
	Backside liner	None	
2	Exit cone	Not inspected	
	Throat	None	
	Throat backup	None	
	Inlet	None	
	Nose	None	
	Backside liner	None	
3	Exit cone	None	
	Throat	None	
	Throat backup	None	
	Inlet	None	
	Nose	None	
	Backside liner	None	
4	Exit cone	None	
	Throat	Small voids near OD, 1 inclusion	Removed during final machining
	Throat backup	None	
	Inlet	None	
	Nose	None	
	Backside liner	Several small voids	Use as is
5	Exit cone	Retainer ring - None Aft, mid and fwd rings not inspected	
	Throat	Small high density inclusion throughout	Use as is, typical of material
	Throat backup	Not inspected (not fabricated as separate part)	
	Inlet	Small high density inclusions throughout	Use as is, typical of material
	Nose	None	
	Backside liner	None	
6	Exit cone	None	
	Throat	None	
	Throat backup	Numerous delaminations and separations	Use as is
	Inlet	Surface porosity	Use as is
	Nose	Small delamination near OD	Use as is
	Backside liner	None	Use as is

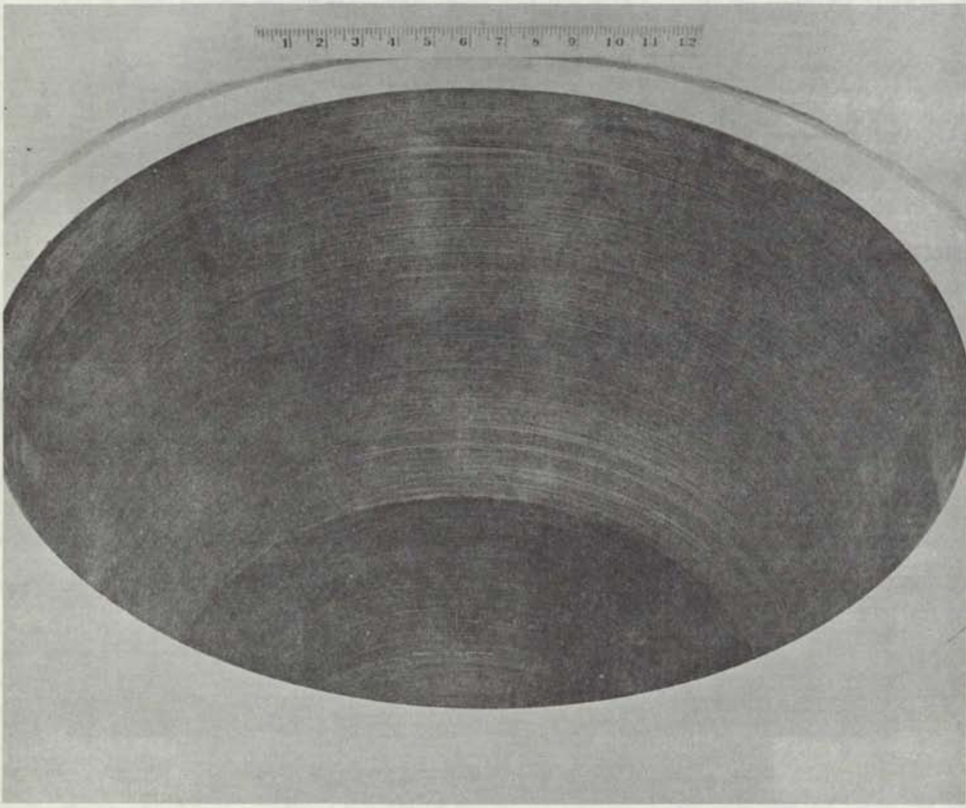


Figure 101. Nozzle No. 1 Exit Cone Assembly

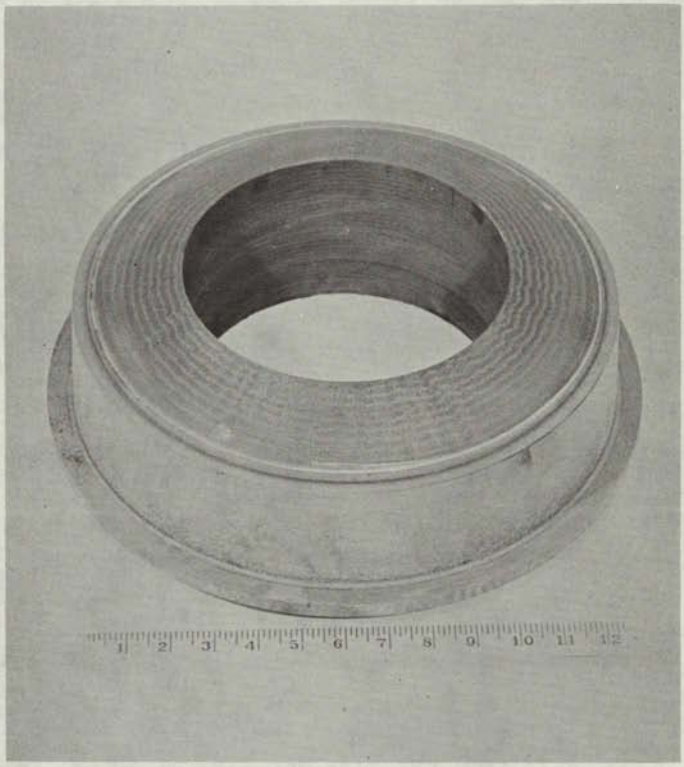


Figure 102. Nozzle No. 1 Throat and Backup Assembly

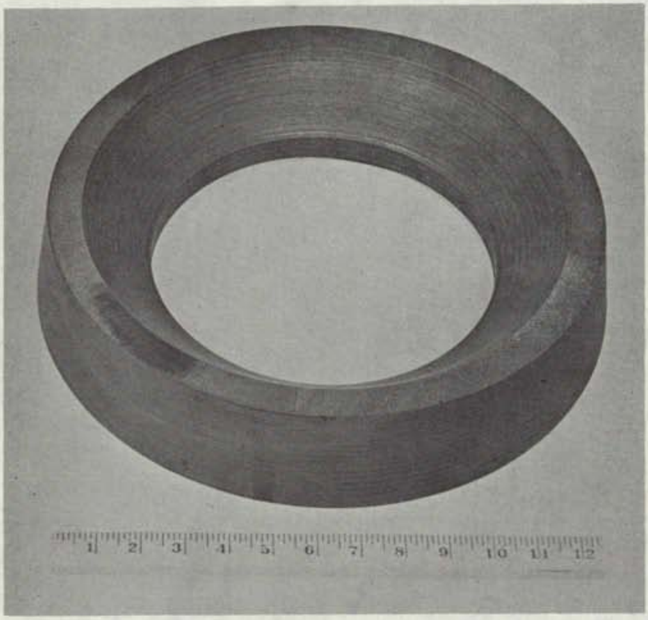


Figure 103. Nozzle No. 1 Inlet Ring

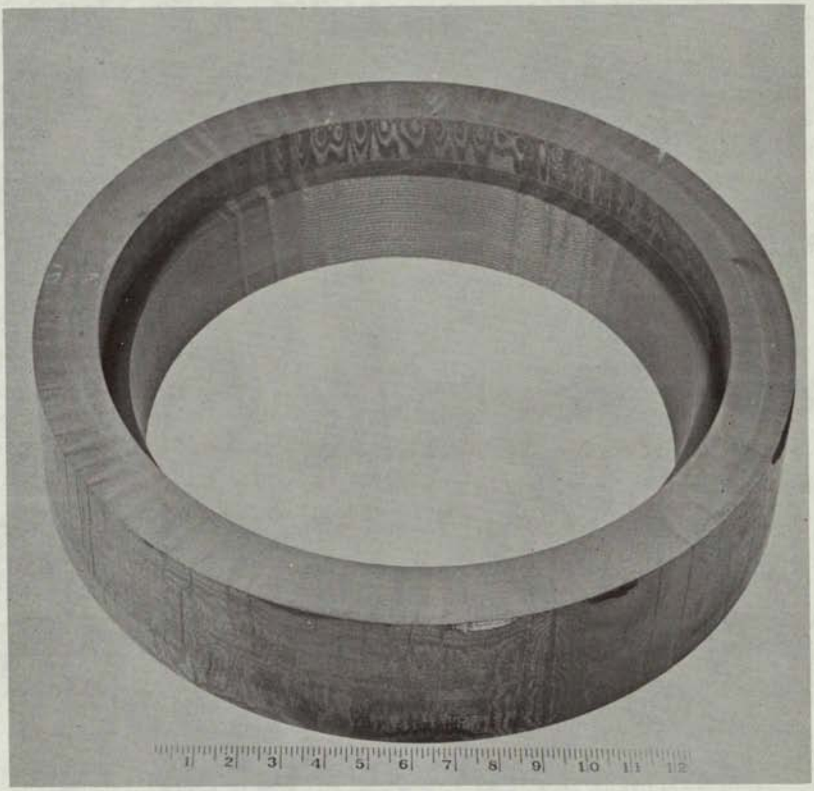


Figure 104. Nozzle No. 1 Nose

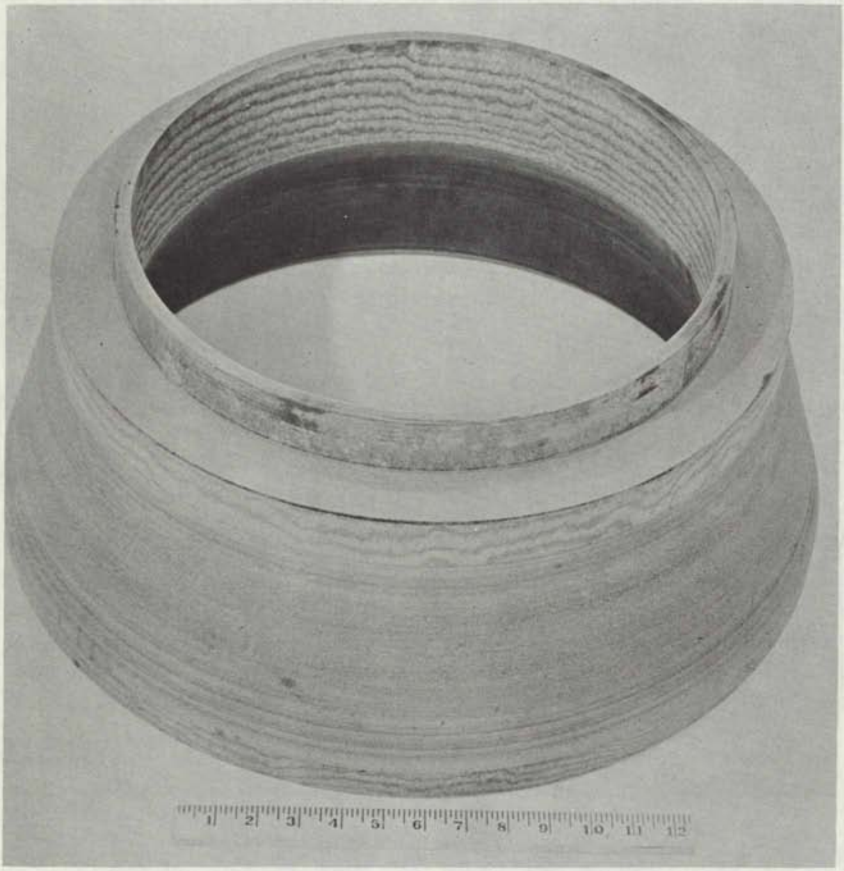


Figure 105. Nozzle No. 1 Backside Insulation

Figure 106. Nozzle No. 1 Final Assembly (View A)

Figure 107. Nozzle No. 1 Final Assembly (View B)

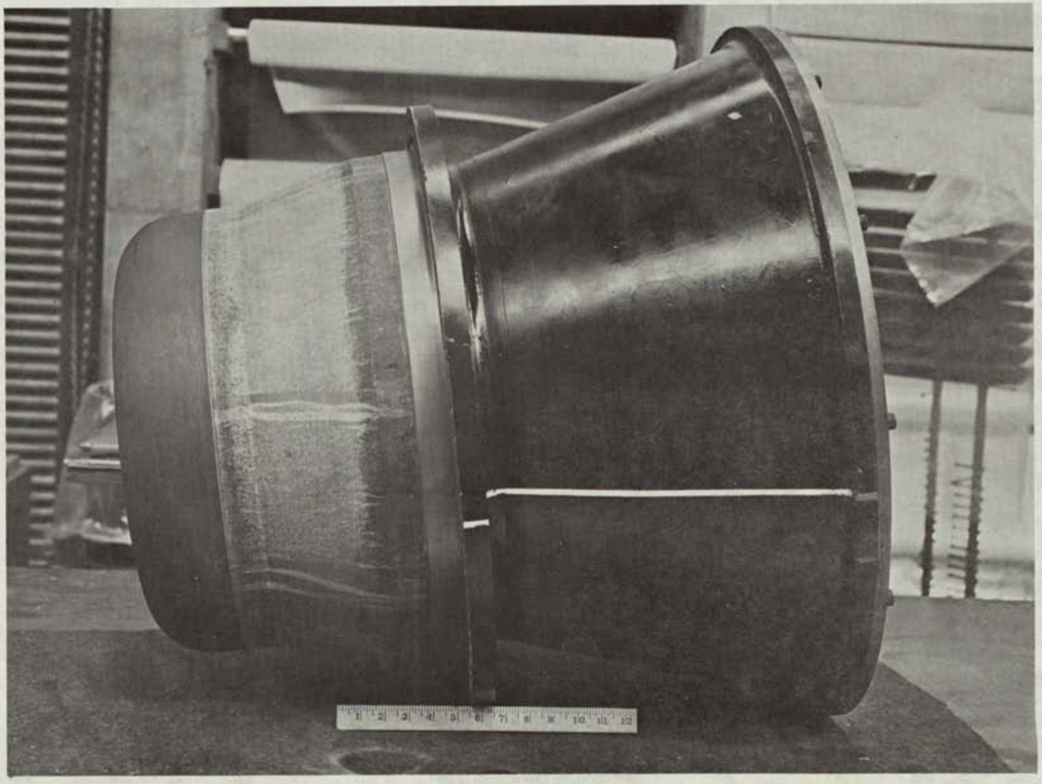


Figure 108. Nozzle No. 3 (View A)

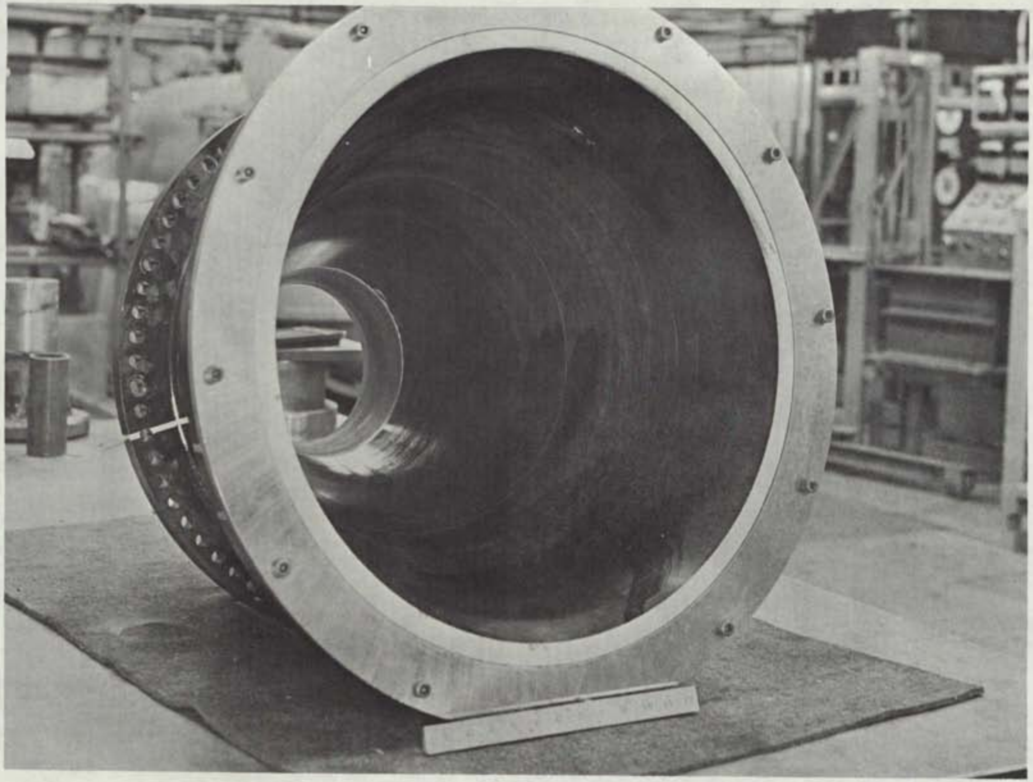


Figure 109. Nozzle No. 3 (View B)

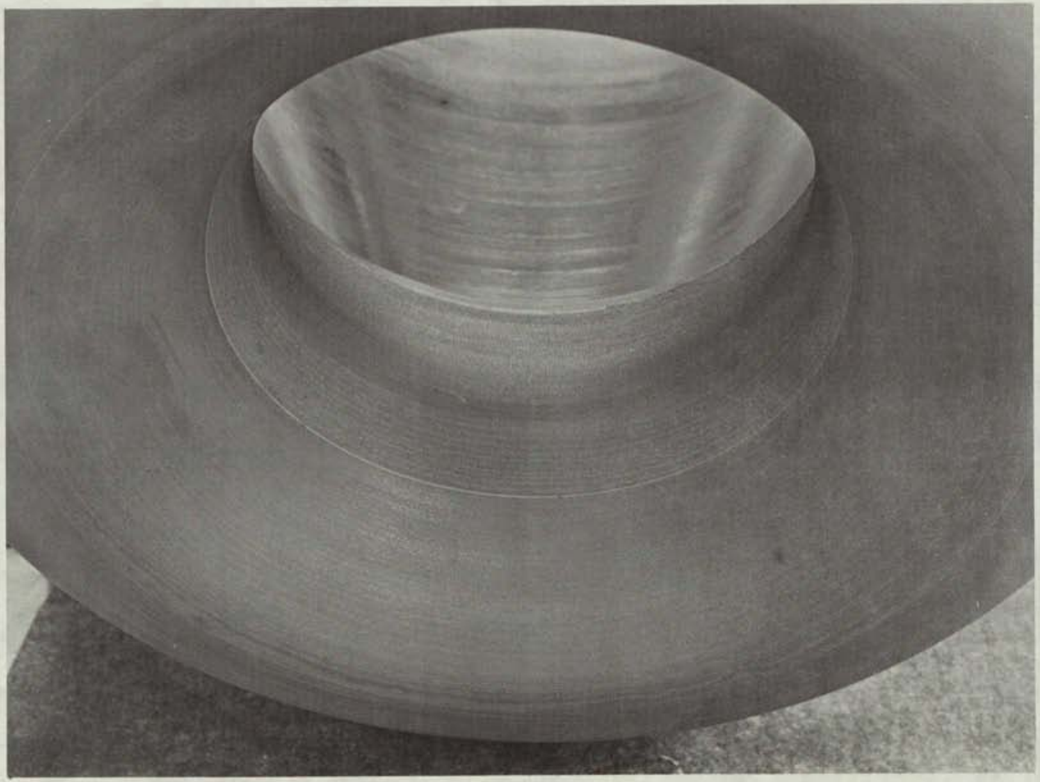


Figure 110. Nozzle No. 3 (View C)

Figure 111. Nozzle No. 4 (View A)

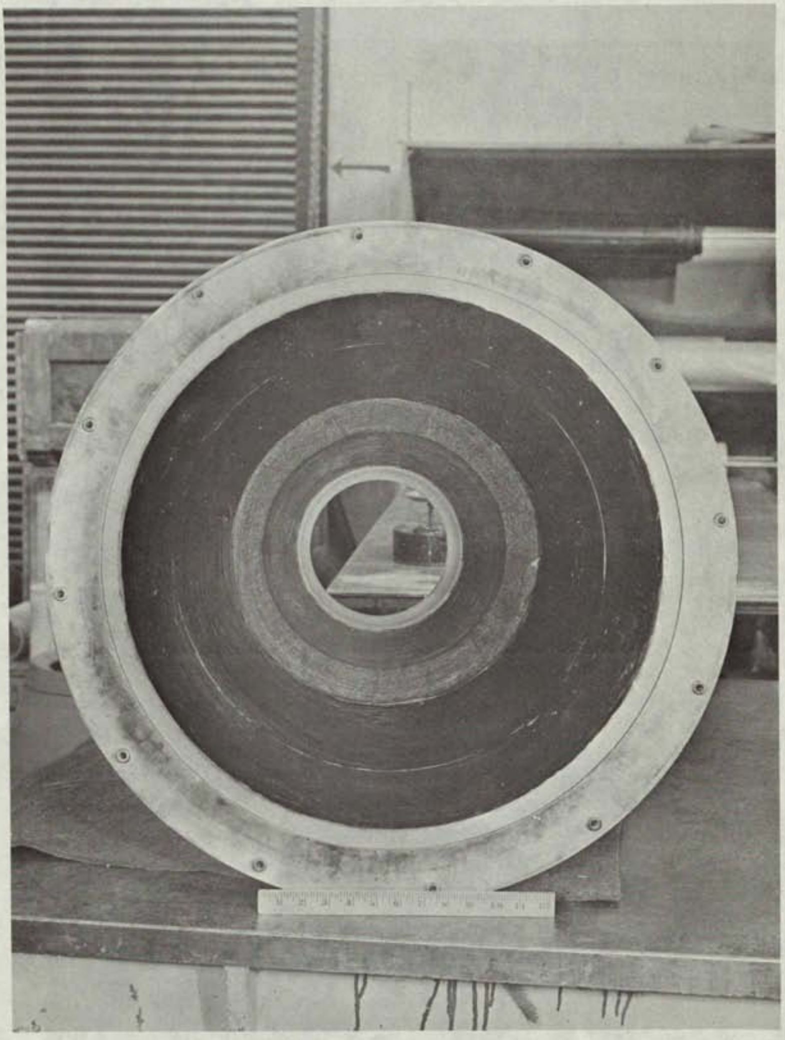


Figure 112. Nozzle No. 4 (View B)

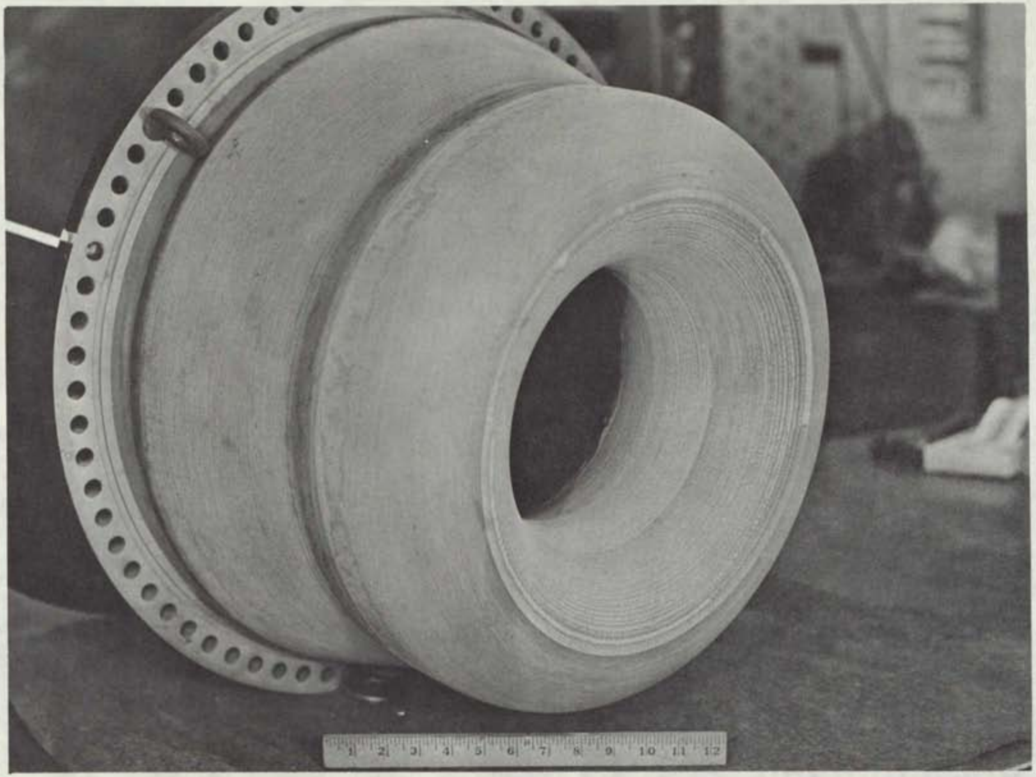


Figure 113. Nozzle No. 4 (View C)

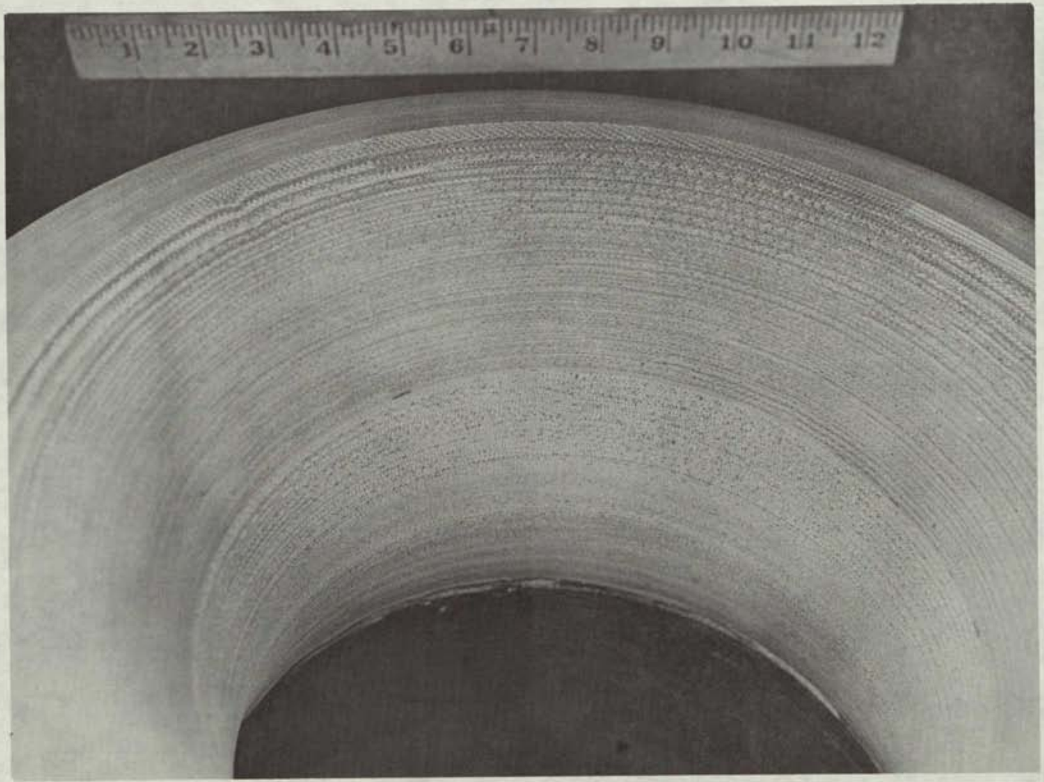


Figure 114. Nozzle No. 4 (View D)

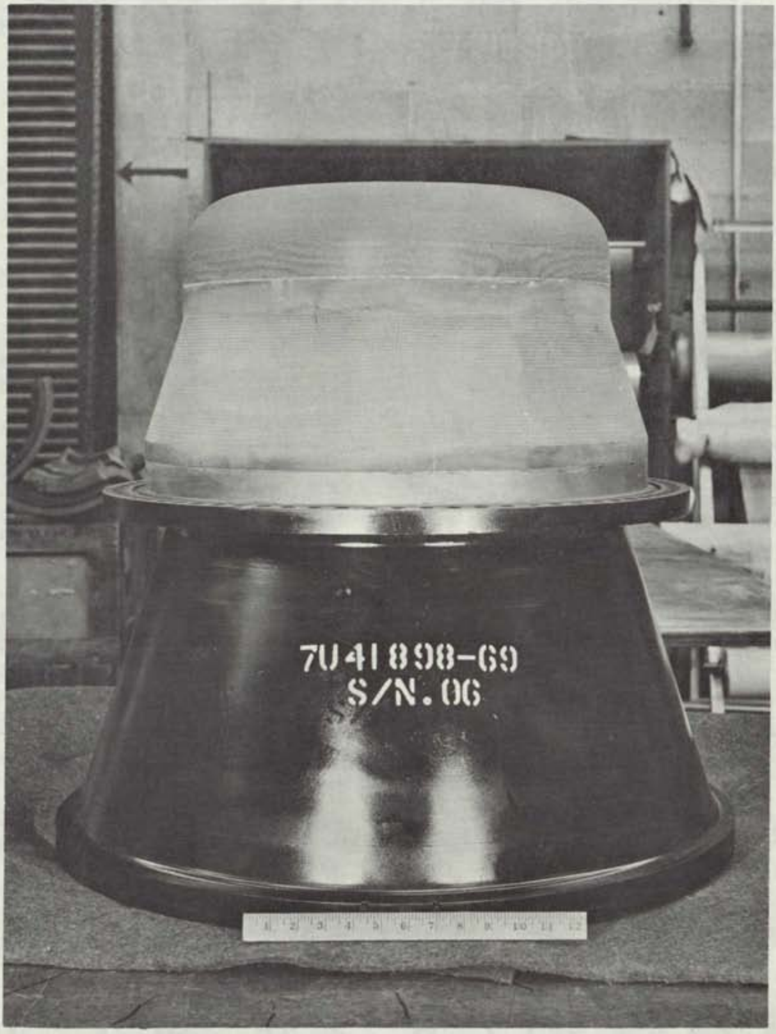


Figure 115. Nozzle No. 6 Before Test (View A)

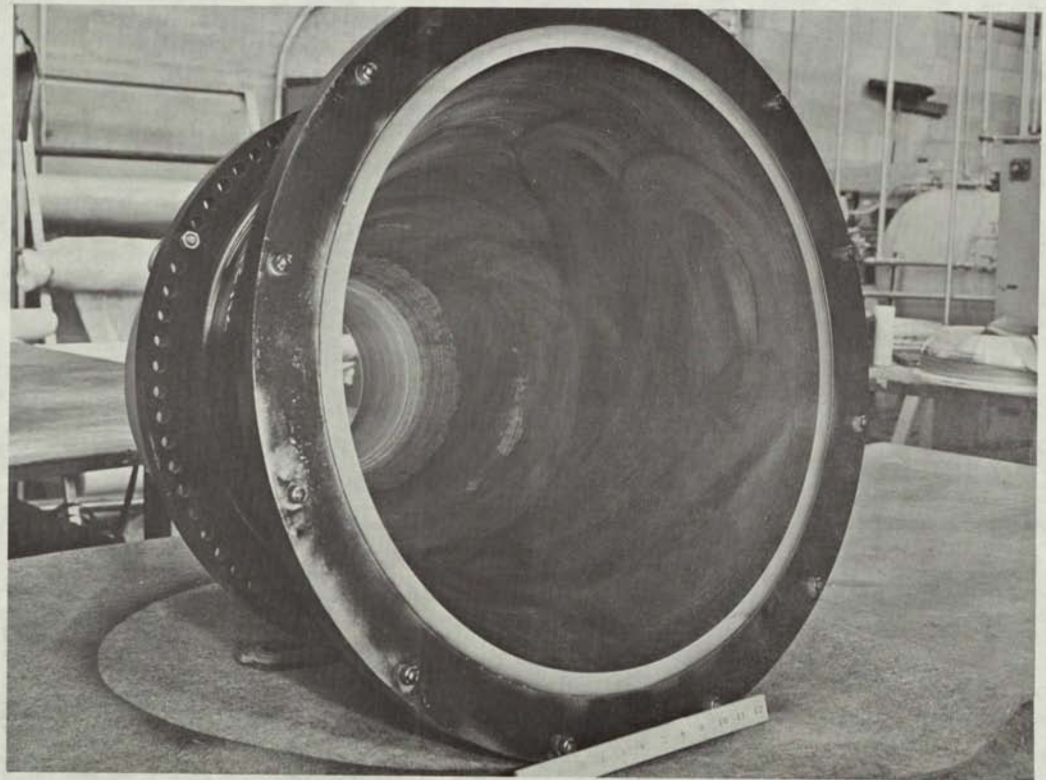


Figure 116. Nozzle No. 6 Before Test (View B)

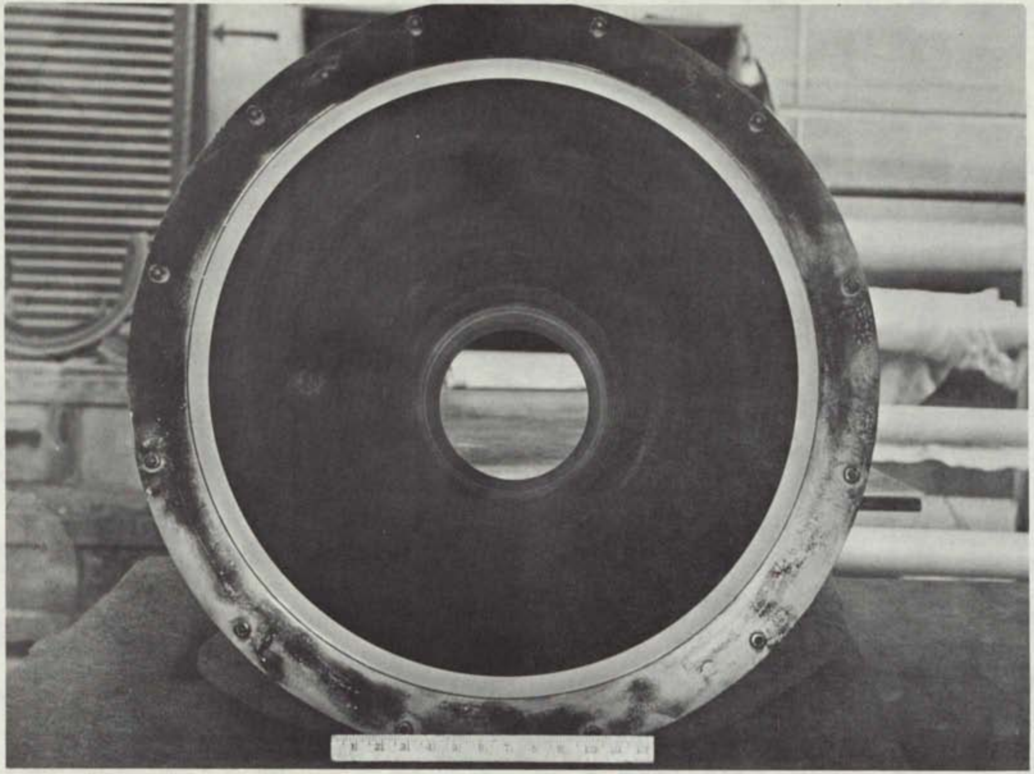


Figure 117. Nozzle No. 6 Before Test (View C)

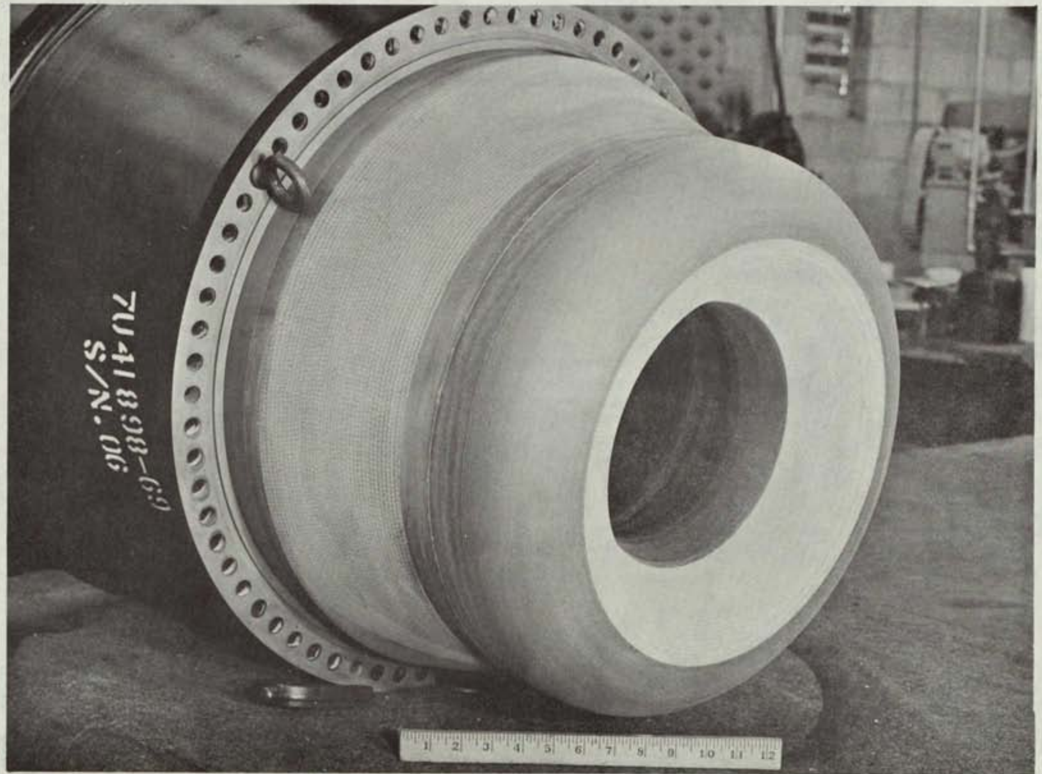


Figure 118. Nozzle No. 6 Before Test (View D)

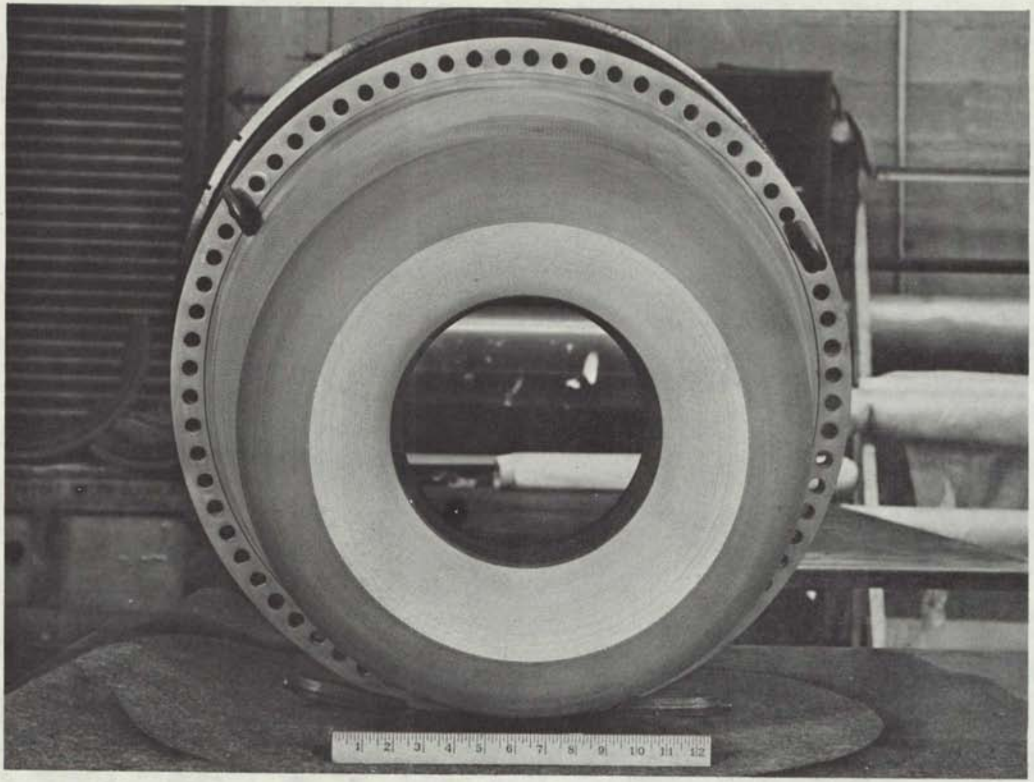


Figure 119. Nozzle No. 6 Before Test (View E)

TABLE 40

FINAL ASSEMBLY DISCREPANCIES, SUBSCALE NOZZLES

Nozzle No.	Discrepancy	Disposition
1	OD of exit cone overwrap debulked excessively, causing undersize condition.	Trowelled UF-1155 (silica filled epoxy polyamide) on cone, cured, and remachined to print.
	Gap between throat and exit cone up to 0.087 in. wide.	Filled in with UF-1120 (asbestos filled epoxy polysulfide).
2	Gap between exit cone segments up to 0.015 in. wide. Print specified 0 - 0.005.	Used as is.
3	Groove gouged around aft part of throat during final machining, 0.080 in. deep by 0.250 in. wide.	Hand sanded to blend in smoothly with exit cone.
4	Backside liner machined incorrectly, causing improper fit to steel shell and to other components.	Remachined. Resulted in decrease in part thickness of 1/8 in. and large gap between part and steel shell at aft end by bolt flange. Gap was filled in with UF-1120 (asbestos filled epoxy polysulfide).
	During cure of exit cone liner, forward portion debulked excessively. When skim cut, part was 0.20 in. thinner than specified.	Increased thickness of overwrap by 0.20 inch.
	Inner surface of aft exit cone was rough and nonuniform after cure.	Sand blasted and applied epoxy polysulfide smoother compound.
5	Backside liner machined incorrectly, causing improper fit to steel shell.	Remachined. Resulted in decrease in part thickness of 1/8 in. Used as is.
	Gap between throat segments up to 0.015 in. wide. Print specified 0 - 0.005.	Used as is.
6	Backside liner intentionally shifted 0.10 in. forward during final fitting.	Used as is.
	To insure proper fit, exit cone was shifted forward 0.10 in., resulting in a 0.10 in. gap between exit cone and steel aft retainer plate.	Used as is.

Figure 120. Nozzle No. 2 LCCM-2626 Molded Cylinders

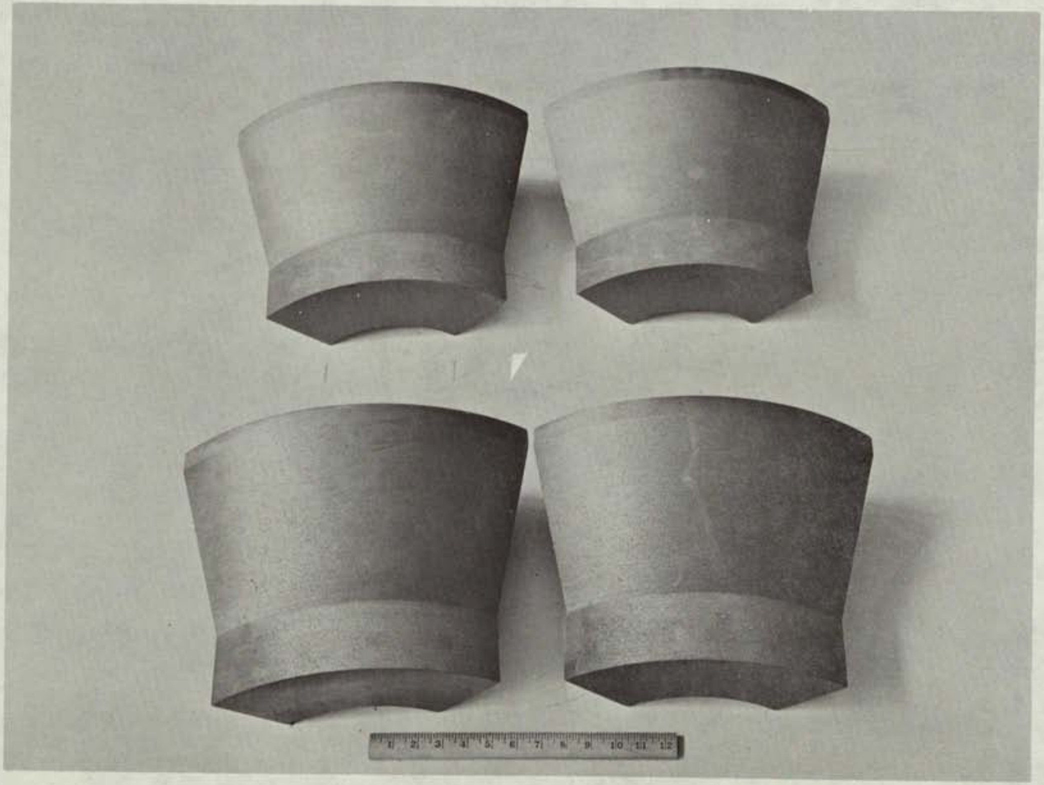


Figure 121. Nozzle No. 2 Four Mating Exit Cone Segments

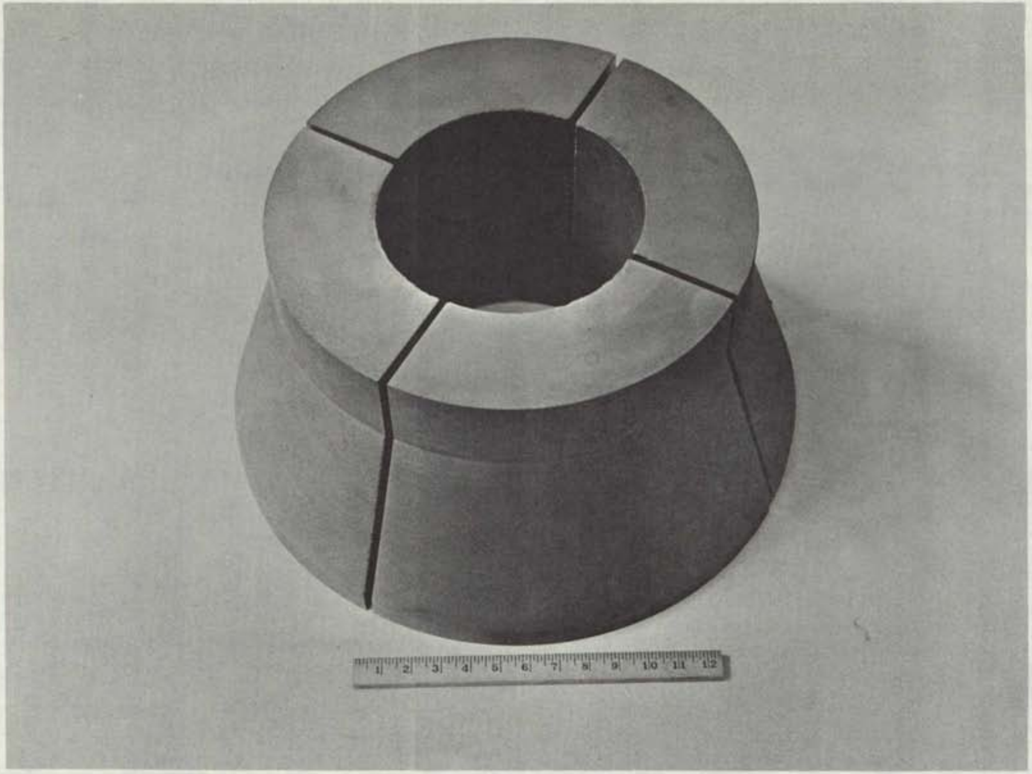


Figure 122. Nozzle No. 2 Four Mating Exit Cone Segments

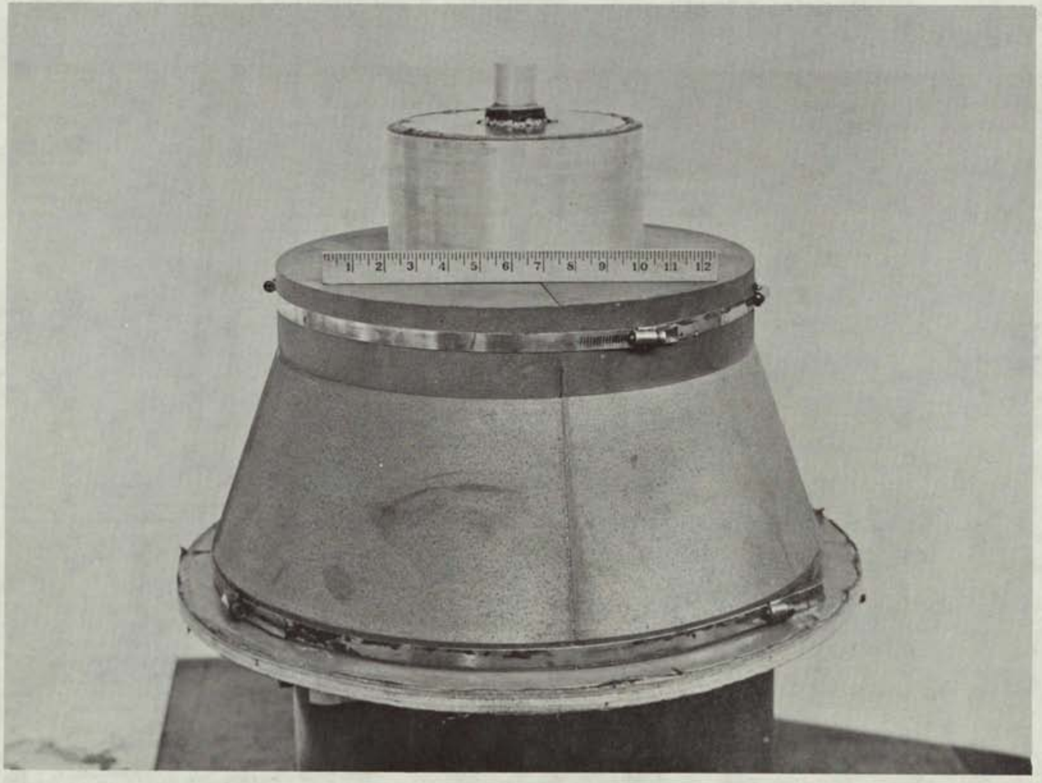


Figure 123. Nozzle No. 2 Exit Cone Segments on Tape Wrapped Mandrel

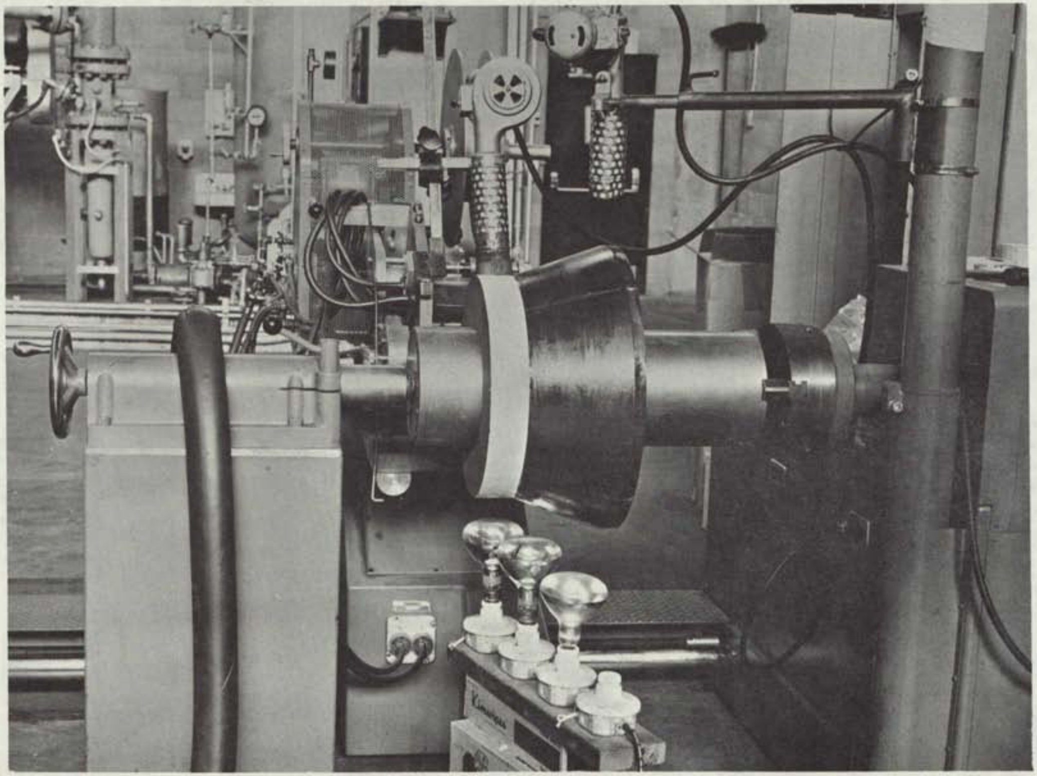


Figure 124. Nozzle No. 2 Installation of Mandrel Prior to Tape Wrap

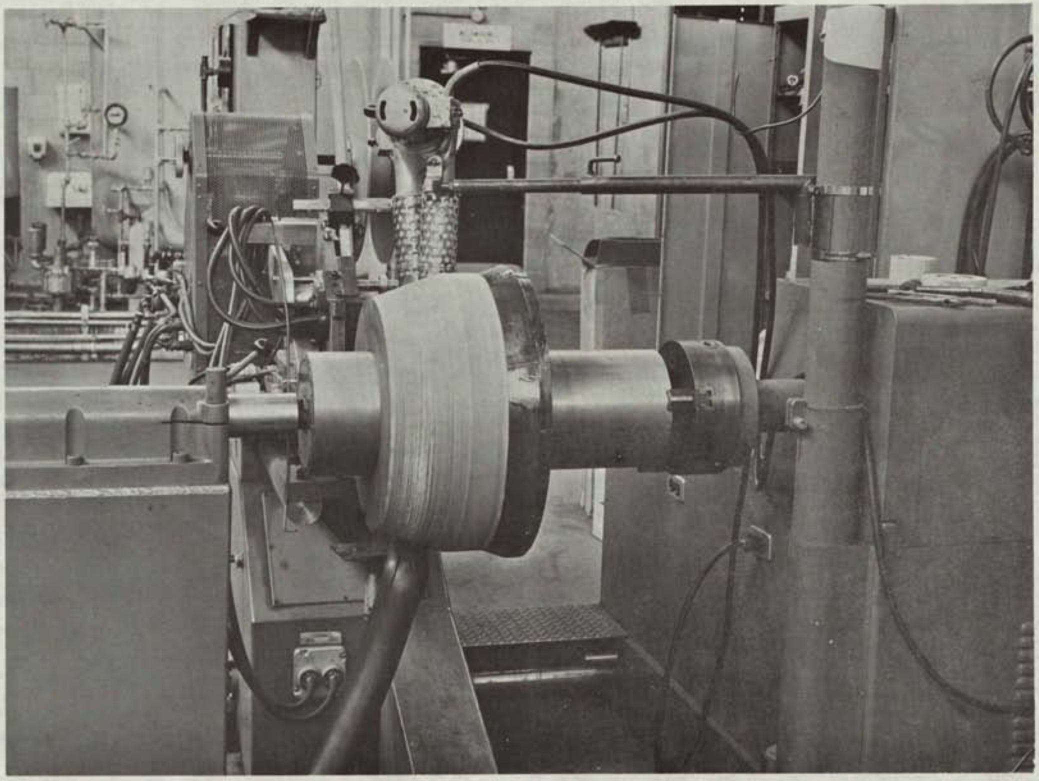


Figure 125. Nozzle No. 2 Tape Wrapping Segments (View A)

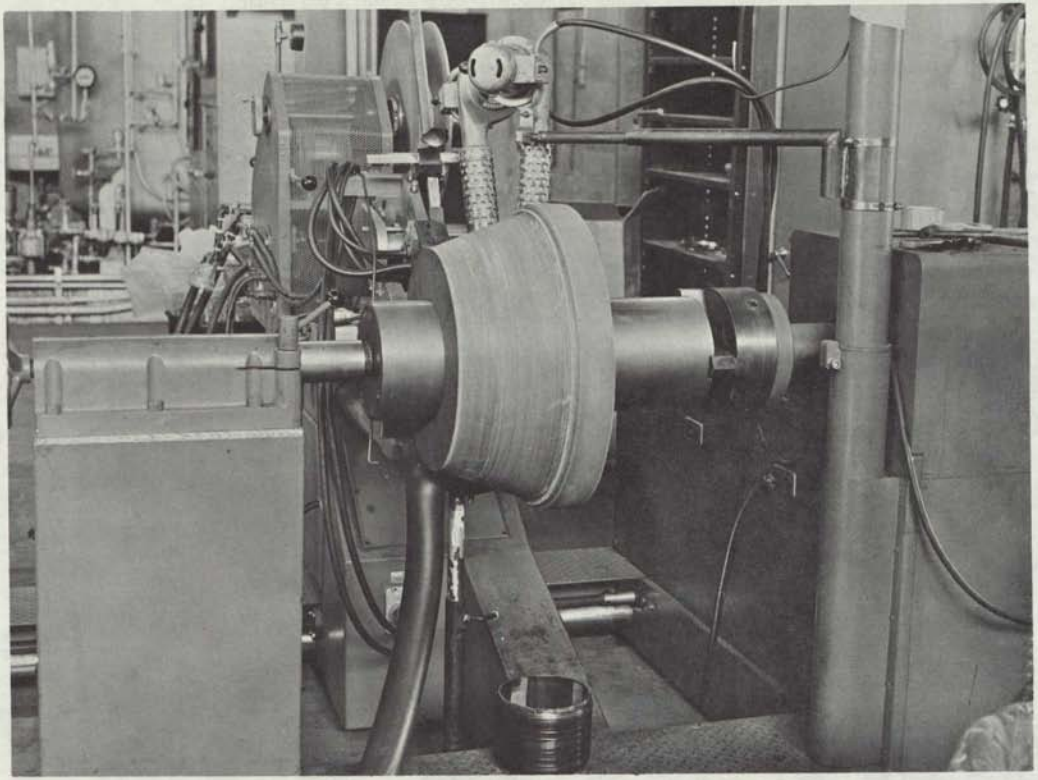


Figure 126. Nozzle No. 2 Tape Wrapping Segments (View B)

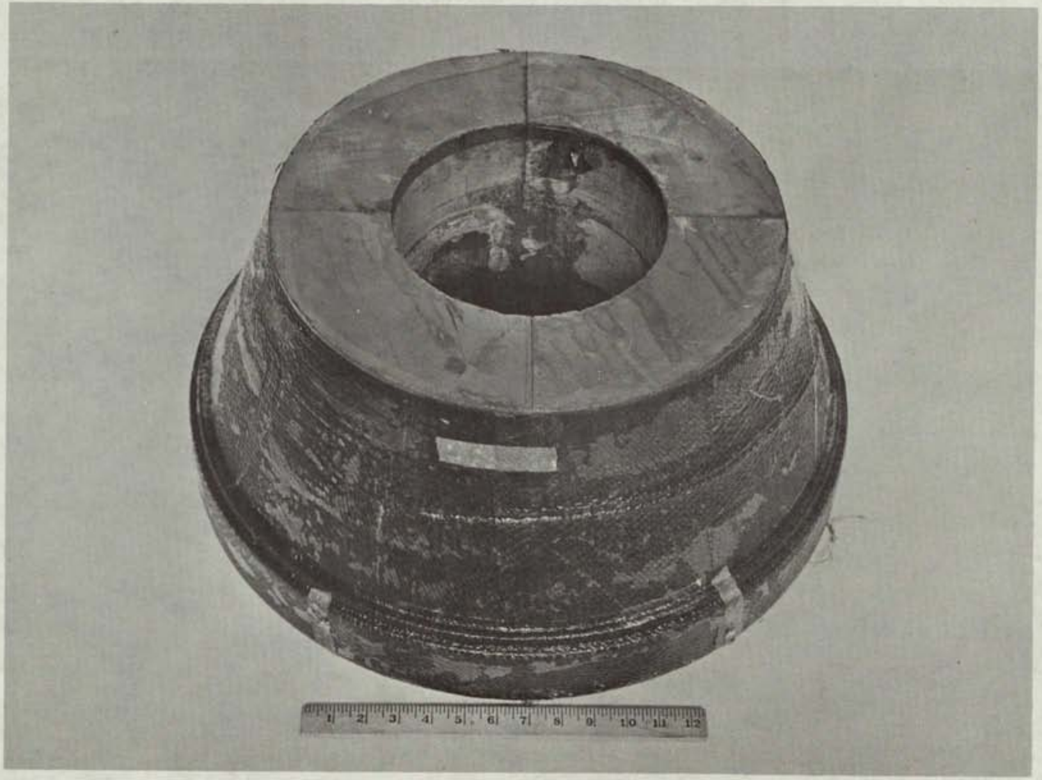


Figure 127. Nozzle No. 2 Cured Middle Segmented Tier

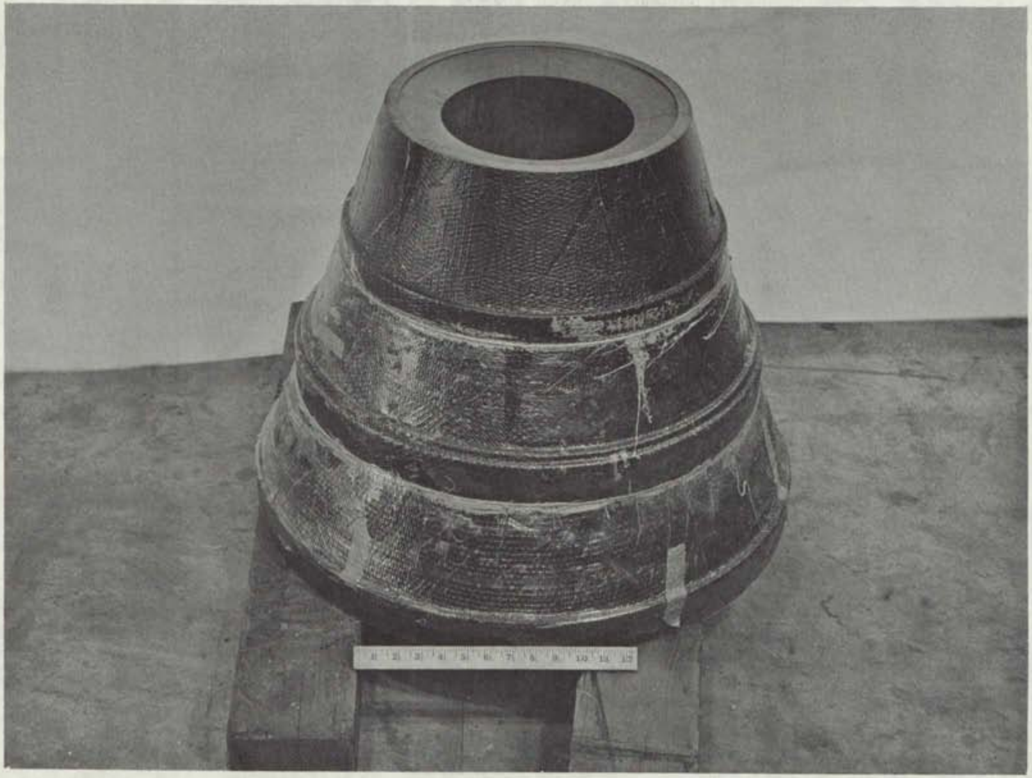


Figure 128. Nozzle No. 2 Assembled Exit Cone Tiers

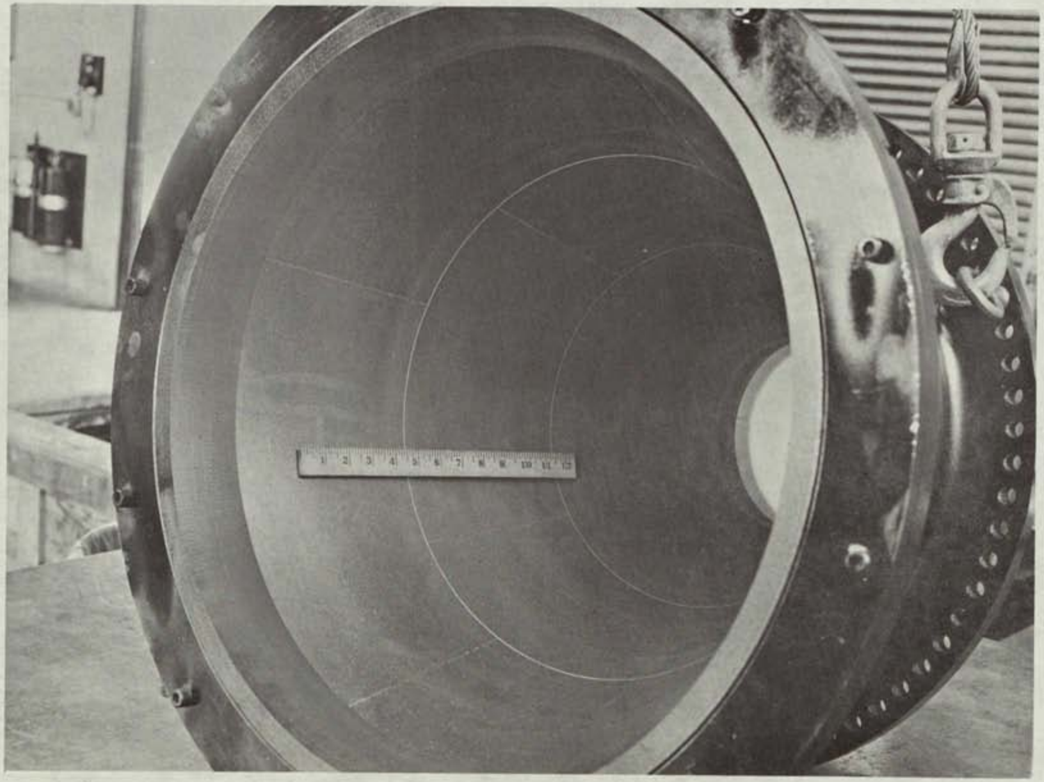


Figure 129. Nozzle No. 2 Installed Segmented Exit Cone

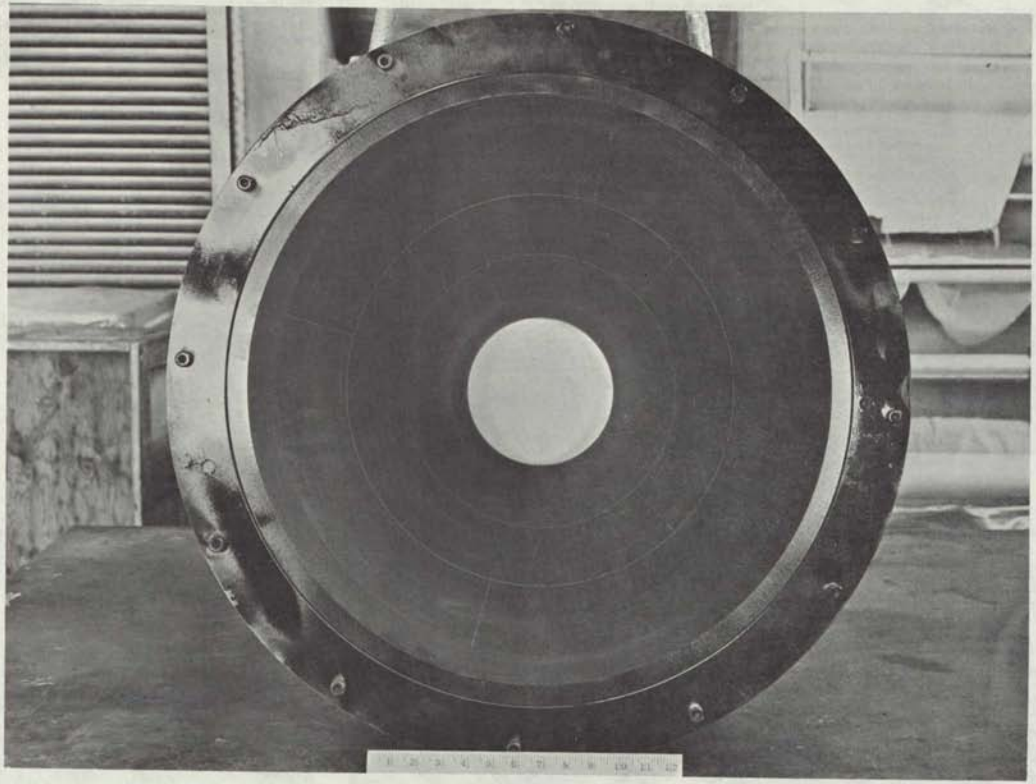


Figure 130. Nozzle No. 2 Segmented Exit Cone

Figure 131. Nozzle No. 2 Nose and Throat View

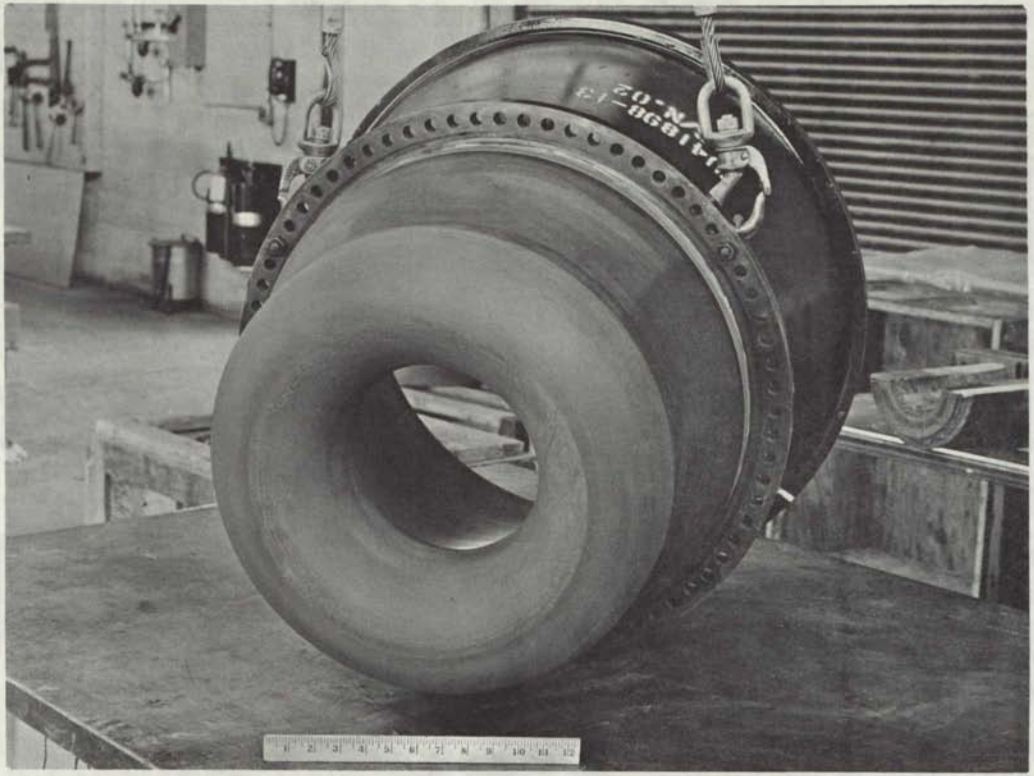


Figure 132. Nozzle No. 2 (View A)

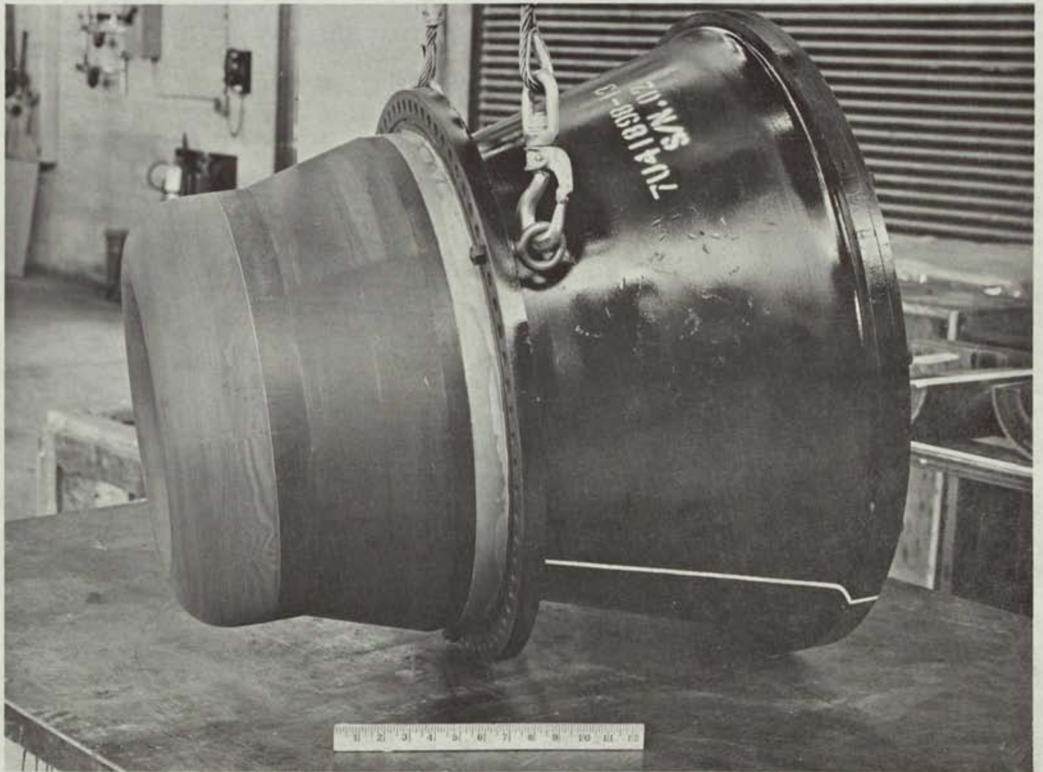


Figure 133. Nozzle No. 2 (View B)

Figure 134. Nozzle No. 5

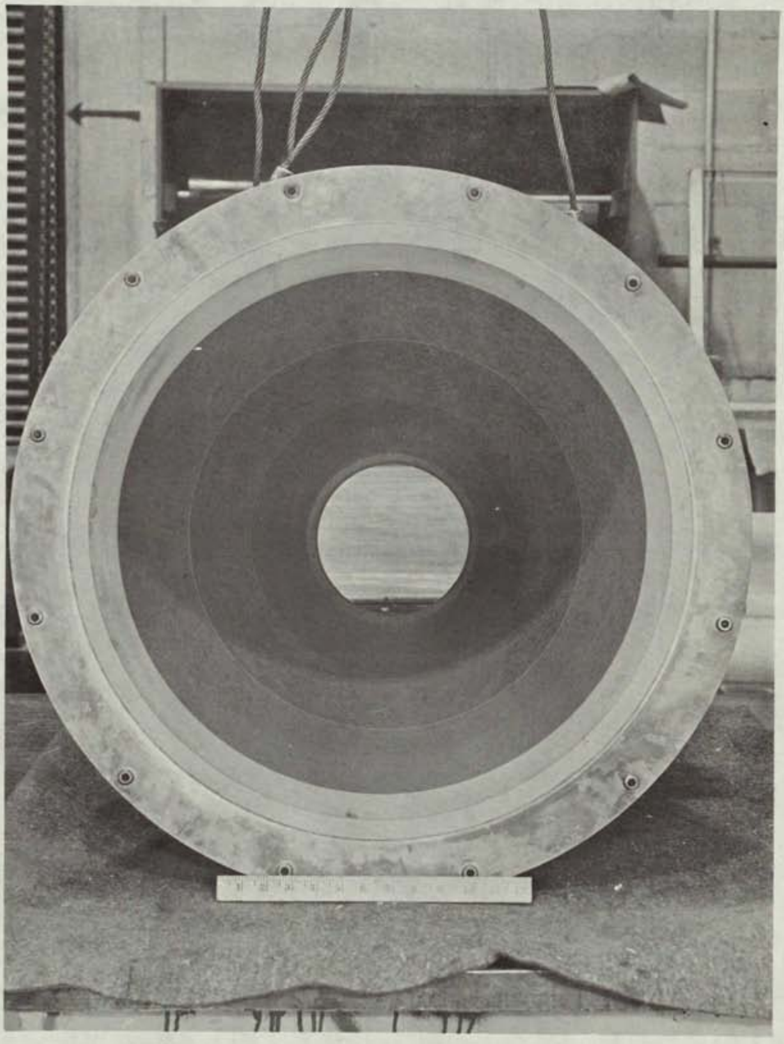


Figure 135. Nozzle No. 5 Tiered Exit Cone (View A)

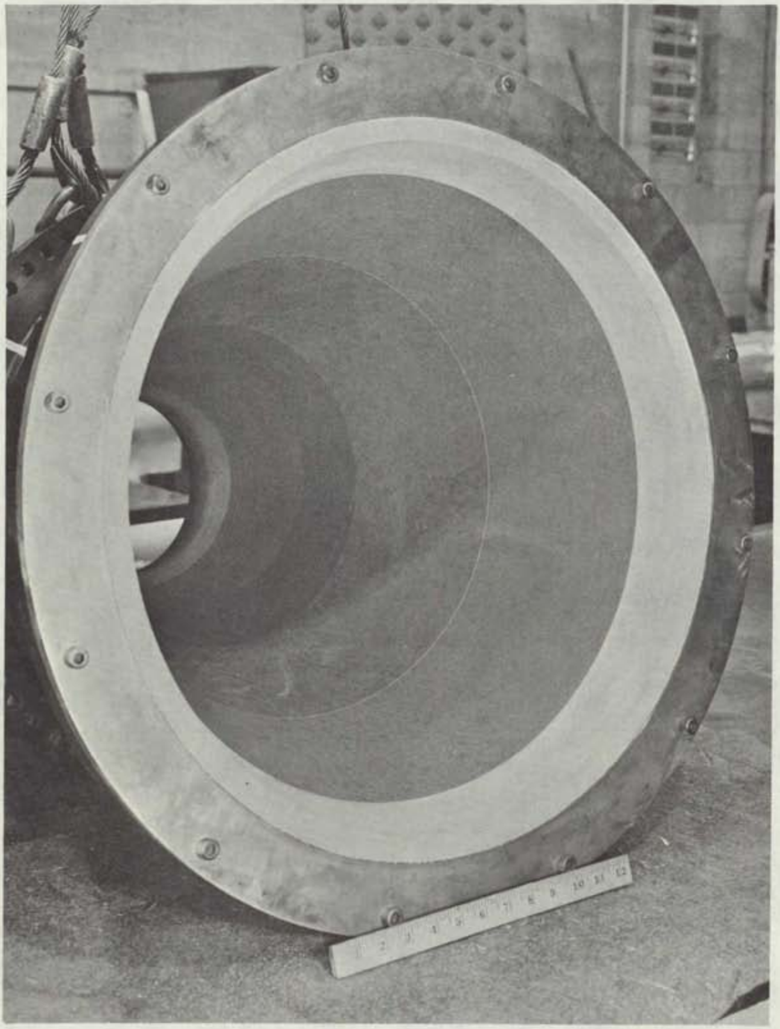


Figure 136. Nozzle No. 5 Tiered Exit Cone (View B)

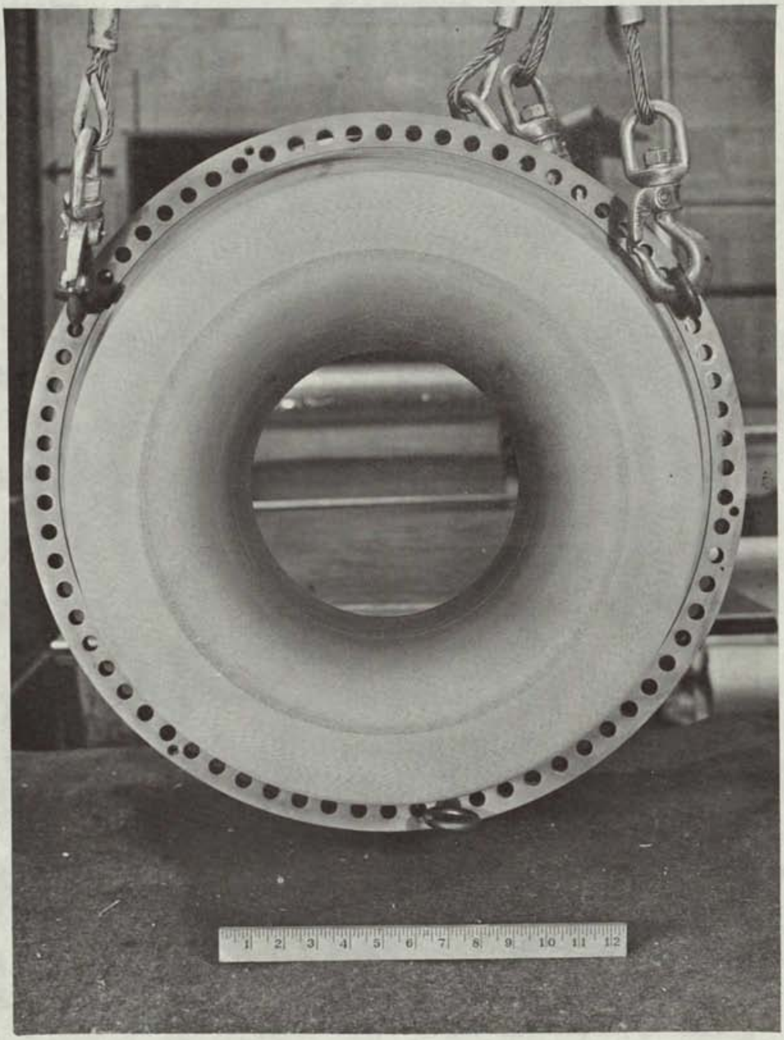


Figure 137. Nozzle No. 5 Nose Inlet and Segmented Throat (View A)

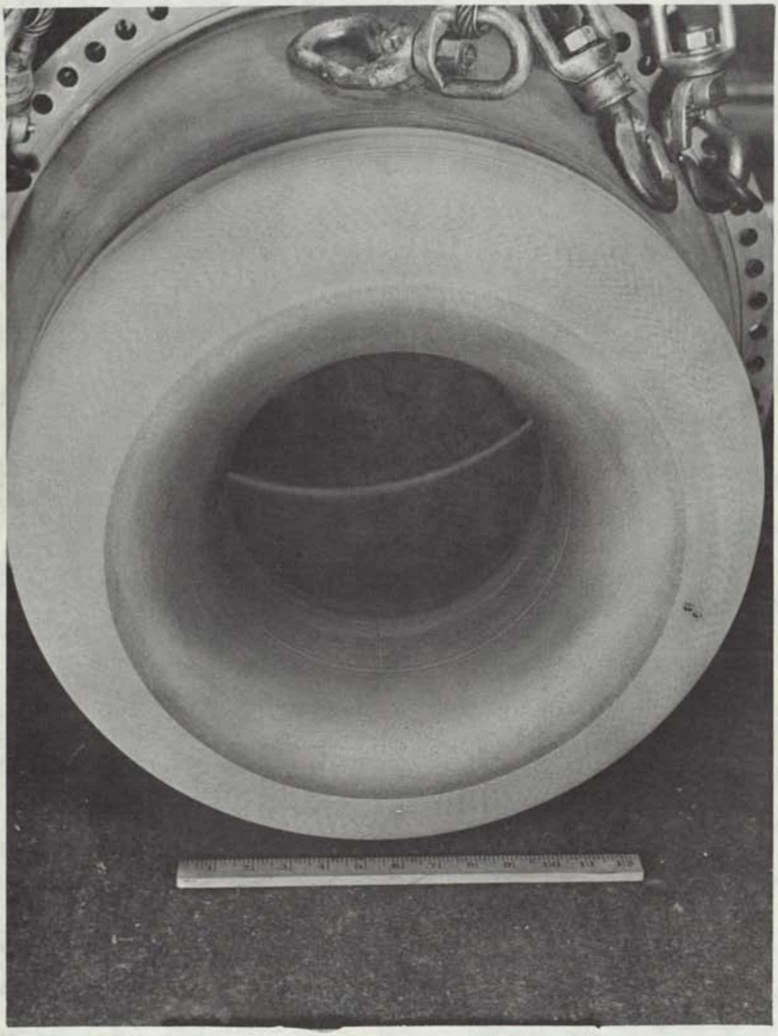


Figure 138. Nozzle No. 5 Nose Inlet and Segmented Throat (View B)

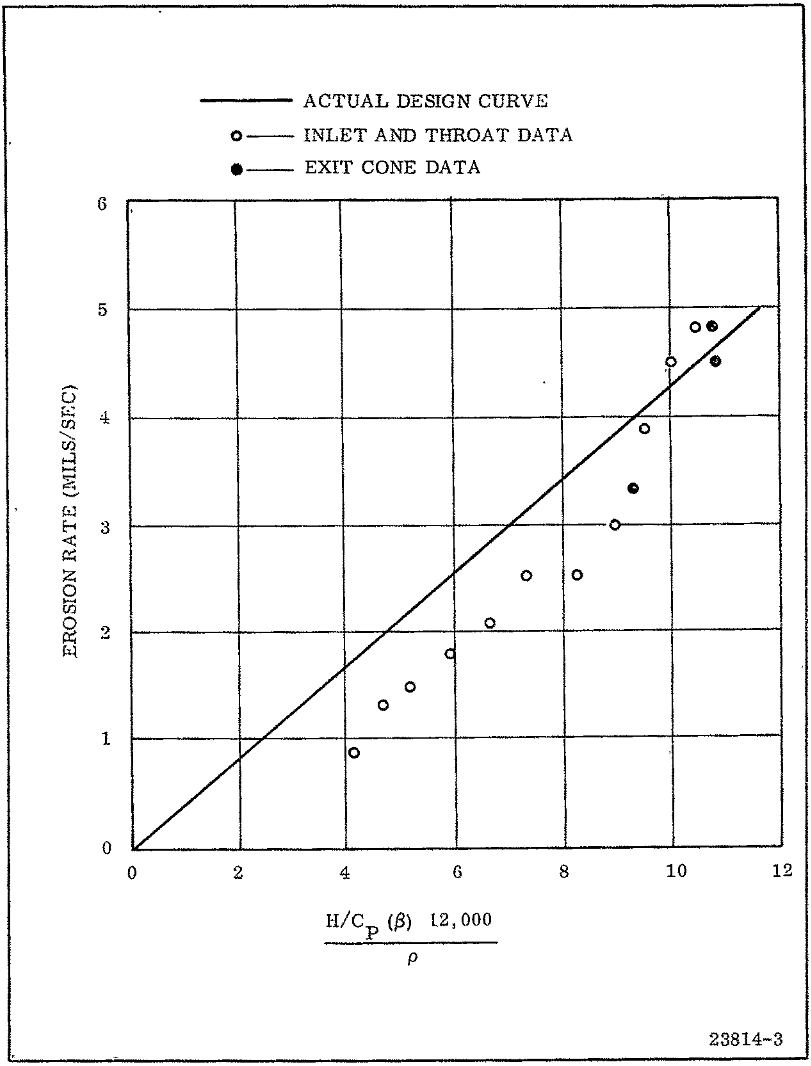


Figure 139. TU-622 Material Performance Curve, 4C-1686 (Carbon Cloth)

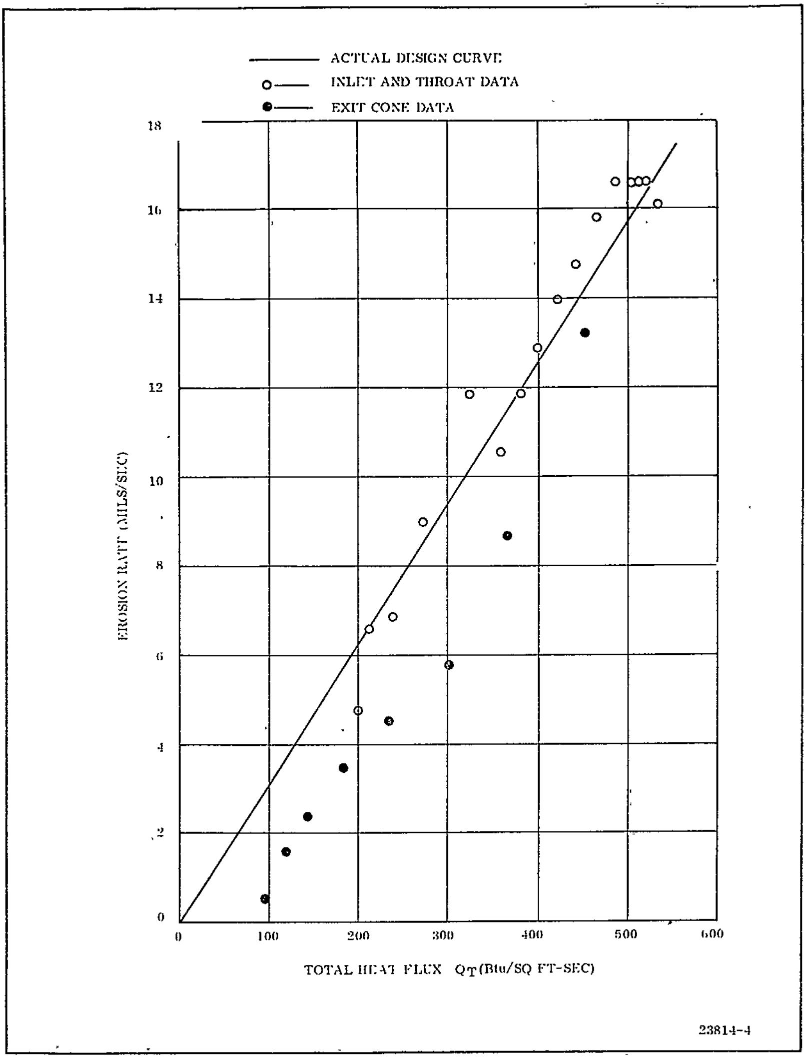


Figure 140. TU-622 Material Performance Curve, SP-8030-96 (Silica)

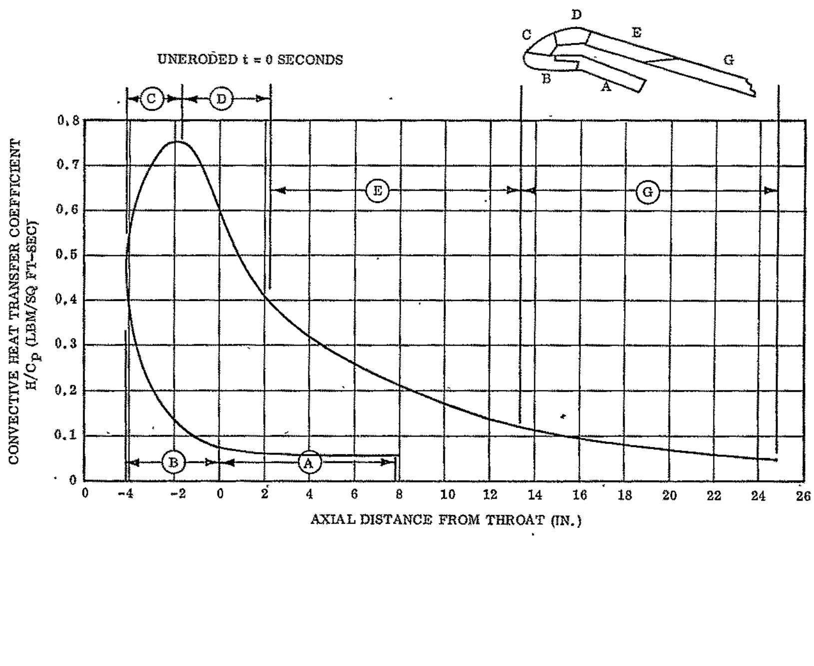


Figure 141. Subscale Nozzle Convective Heat Transfer Coefficient, Carbonaceous Material

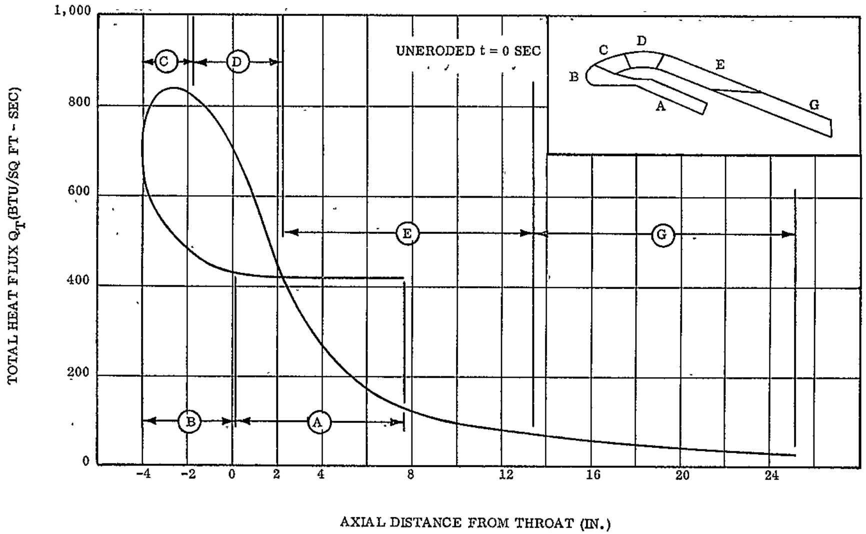


Figure 142. Subscale Nozzle Total Heat Flux, Asbestos Material

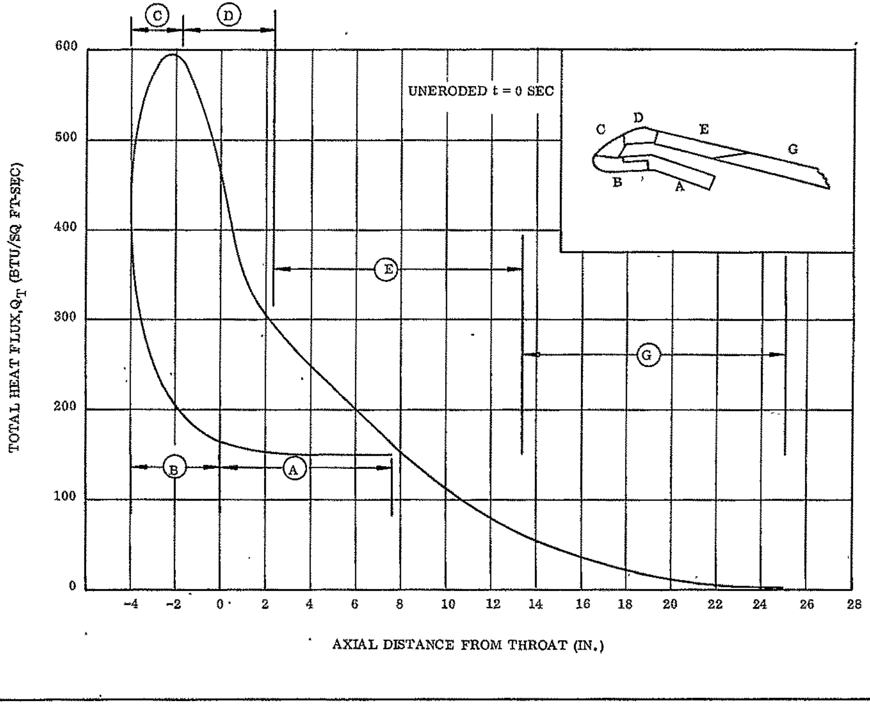


Figure 143. Subscale Nozzle Total Heat Flux, Silica Material

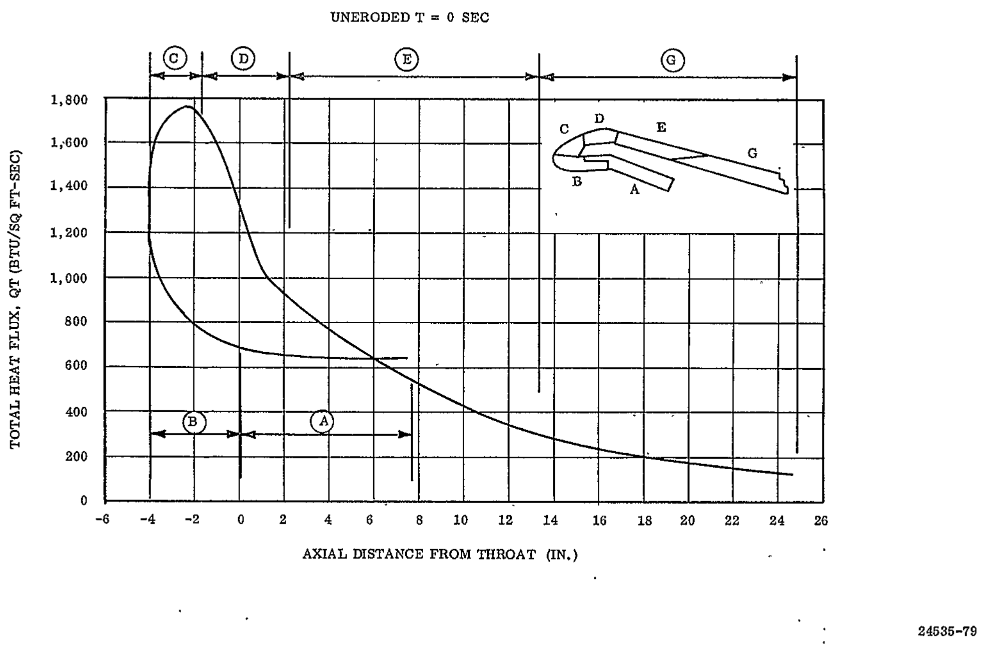


Figure 144. Subscale Nozzle Total Heat Flux, Canvas and Paper Material

TABLE 41

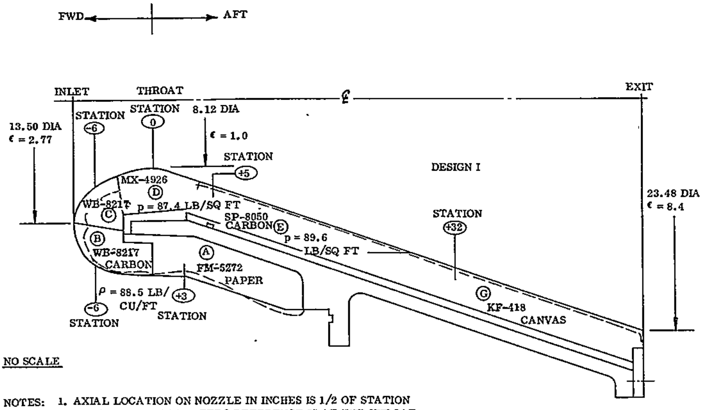
PREDICTED VERSUS ACTUAL EROSION RATE

Material	Subscale Nozzle Area Location	Predicted Erosion Rate (Mils/Sec)	Actual Erosion Rate (Mils/Sec)	Actual E. R. Factor/Predicted E. R.	Allowable Erosion Factor Increase		
					Nozzle Type Factor X	Heat Sink Factor =	Total Factor
LCCM-2626 Graphite Particle 1,000 psi Cure	Throat (#2)	3.00	8.52	2.84	1.50	2.25	3.38
	Inlet (#5)	3.50	8.57	2.45	1.50	2.25	3.38
	Throat (#6)	3.00	9.94	3.31	1.50	2.25	3.38
LCCM-2626X Graphite Particle 850 psi Cure	Forward Exit (#2)	1.80	8.50	4.72	1.00	2.25	2.25
	Middle Exit (#2)	0.65	5.70	8.77	1.00	2.25	2.25
	Aft Exit (#2)	0.18	-2.90	-16.11	1.00	2.25	2.25
	Forward Exit (#5)	1.80	18.33	10.18	1.00	2.25	2.25
23-RPD Asbestos	Submerged Liner (#1)	10.00	6.40	0.64	1.00	1.00	1.00
	Forward Exit (#4)	6.70	18.02	2.69	1.00	1.00	1.00
SP-8030-96	Aft Exit (#3)	0.70	2.13	3.04	1.00	1.00	1.00

NOTE:

1. If Erosion Rate Factor is 1.00 or greater, the Actual Erosion is higher than Predicted Erosion.

2. If Erosion Rate Factor is under 1.00 or a minus number, the Actual Erosion is lower than Predicted Erosion.



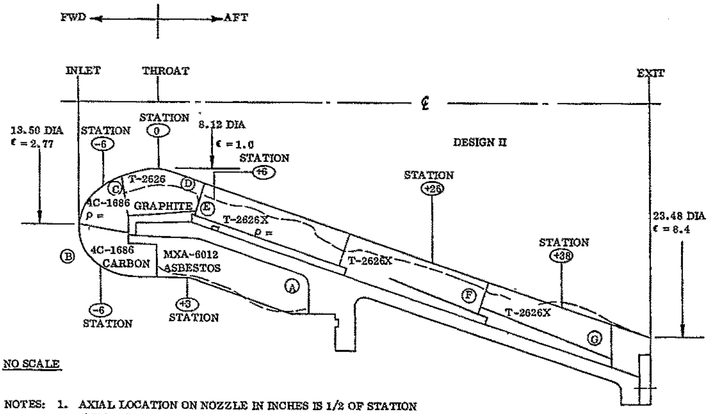
NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE

2. PROPELLANT BLOWING COEFFICIENT (β) = 0.098

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS h/cp	h/cp (β) 12,000 / ρ	Q_T	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 A	+1.50	—	—	760	(NOT TESTED IN TU-622)	2.46
-6 B	-3.00	0.205	2.73	—		1.40
-6 C	-3.00	0.700	9.33	—		10.90
0 D	0	0.600	8.07	—		8.09
+5 E	+2.50	0.288	2.78	—		3.16
+32 G	+16.00	—	—	240	(NOT TESTED IN TU-622)	1.05

24535-57

Figure 145. Nozzle No. 1 Material Performance Evaluation



NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE.

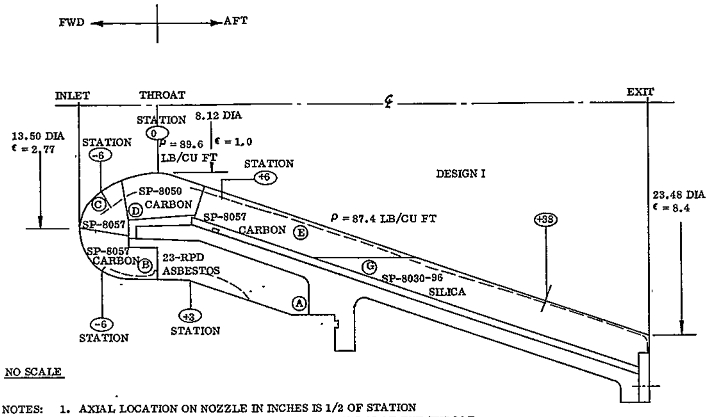
2. PROPELLANT BLOWING COEFFICIENT (β) = 0.098

3. MINUS (-) SIGN INDICATES WALL THICKNESS INCREASED

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS h/c_p	$\frac{h/c_p\,(\beta)\,12,000}{\rho}$	Q_T	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 Ⓐ	+1.50	--	--	515	(NOT TESTED IN TU-622)	1.74
-6 Ⓑ	-3.00	0.205	2.98	--	1.40	2.95
-6 Ⓒ	-3.00	0.700	10.12	--	4.90	8.35
0 Ⓓ	0	0.600	6.32	--	3.00	8.52
+6 Ⓔ	+3.00	0.355	3.72	--	1.80	8.50
+26 Ⓕ	+13.00	0.122	1.28	--	0.65	5.70
+38 Ⓖ	+19.00	0.075	1.79	--	0.18	-2.90[3]

24535-52

Figure 146. Nozzle No. 2 Material Performance Evaluation



NO SCALE

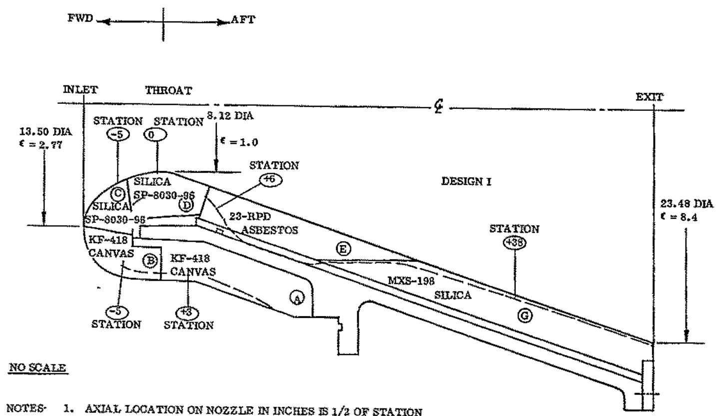
NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE NUMBER IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE.

2. PROPELLANT BLOWING COEFFICIENT (β) = 0.098

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS h/cp	$\frac{h/cp\ (\beta)\ 12,000}{\rho}$	Q_T	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 A	+1.50	—	—	515	10.00	6.40
-6 B	-3.00	0.205	2.75	—	2.75	4.44
-6 C	-3.00	0.700	9.41	—	9.41	11.03
0 D	0	0.600	7.88	—	(NOT TESTED IN TU-622)	9.78
+6 E	+3.00	0.360	4.84	—	4.84	4.09
+38 G	+18.00	—	—	22	0.70	2.13

24535-56

Figure 147. Nozzle No. 3 Material Performance Evaluation



NO SCALE

NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE NUMBER IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE.

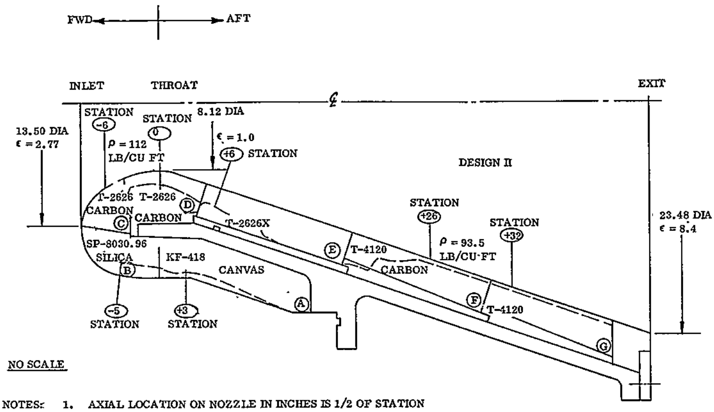
2. PROPELLANT BLOWING COEFFICIENT (ζ) = 0.098

3. INLET C EROSION PATTERN WAS LESS IN THREE OTHER SIMILAR PLANES

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS $\underline{h/cp}$	$\underline{h/cp\ (\beta)\ 12,000}$ / ρ	$\underline{Q_T}$	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 Ⓐ	+1.50	--	--	660	(NOT TESTED IN TU-622)	4.43
-5 Ⓑ	-2.50	--	--	840	(NOT TESTED IN TU-622)	9.02
-5 Ⓒ	-2.50	--	--	592	18.50 [3]	27.87
0 Ⓓ	0	--	--	450	14.00	18.85
+6 Ⓔ	+3.00	--	--	345	6.70	18.02
+38 Ⓖ	+19.00	--	--	17	1.80	1.96

24535-54

Figure 148. Nozzle No. 4 Material Performance Evaluation



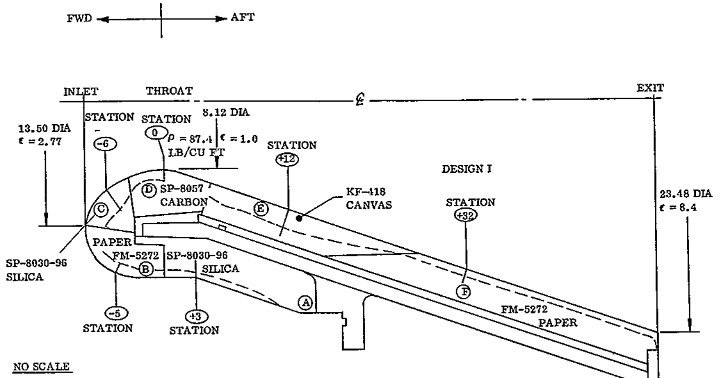
NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE NUMBER IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE.

2. PROPELLANT BLOWING COEFFICIENT (β) = 0.098

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS h/cp	h/cp (β) 12,000 / ρ	Q_T	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 A	+1.50	—	—	660	(NOT TESTED IN TU-622)	3.59
-5 B	-2.50	—	—	225	7.10	10.62
-6 C	-3.00	0.700	7.33	—	3.50	8.57
0 D	0	0.600	6.30	—	3.00	9.94
+6 E	+3.00	0.358	3.76	—	1.80	18.33
+26 F	+13.00	0.120	1.51	—	1.15	1.37
+32 G	+16.00	0.095	1.20	—	0.85	0.51

24535-51

Figure 149. Nozzle No. 5 Material Performance Evaluation



NOTES: 1. AXIAL LOCATION ON NOZZLE IN INCHES IS 1/2 OF STATION (CIRCLED) NUMBER. ZERO REFERENCE NUMBER IS AT THE THROAT. NUMBERS FORWARD OF THROAT ARE NEGATIVE. NUMBERS AFT OF THROAT ARE POSITIVE.

2 PROPELLANT BLOWING COEFFICIENT (β) = 0.098.

STATION	AXIAL LENGTH (IN.)	SUBSCALE AERODYNAMIC PARAMETERS h/c_p	$h/c_p\,(\frac{}{\rho})\,12,000$	Q_T	PREDICTED EROSION RATE FROM TU-622 MATERIAL DESIGN CURVES (MILS/SEC)	ACTUAL TEST EROSION RATE BETWEEN STAR-POINT AND STAR VALLEY (MILS/SEC)
+3 (A)	+1.50	—	—	155	4.85	6.06
-5 (B)	-2.50	—	—	225	(NOT TESTED IN TU-622)	5.83 EST
-6 (C)	-3.00	—	—	575	18.00	23.00
+0 (D)	0	0.60	8.09	--	8.09	9.40
+12 (E)	+6.00	--	—	640	(NOT TESTED IN TU-622)	17.18
+32 (F)	+16.00	—	—	240	(NOT TESTED IN TU-622)	5.50

24535-55

Figure 150. Nozzle No. 6 Material Performance Evaluation

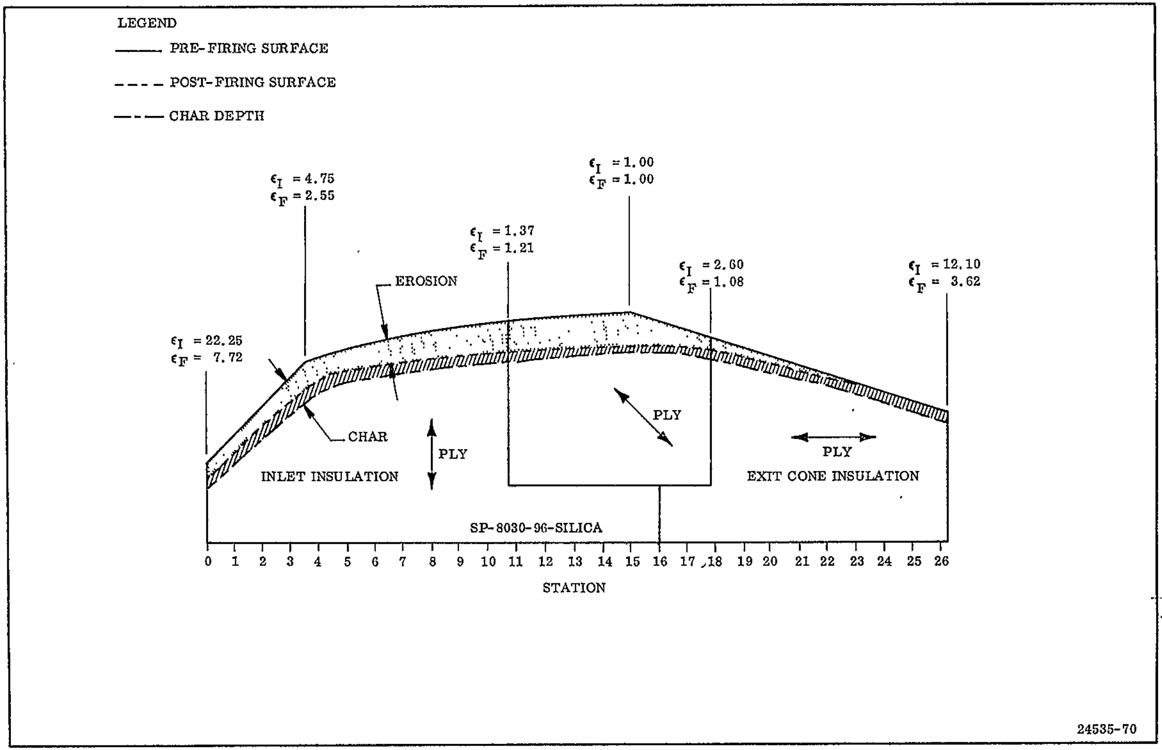


Figure 151. TU-622 Pre and Post-Test Evaluation

Figure 152. Subscale Nozzle-Closure Assembly

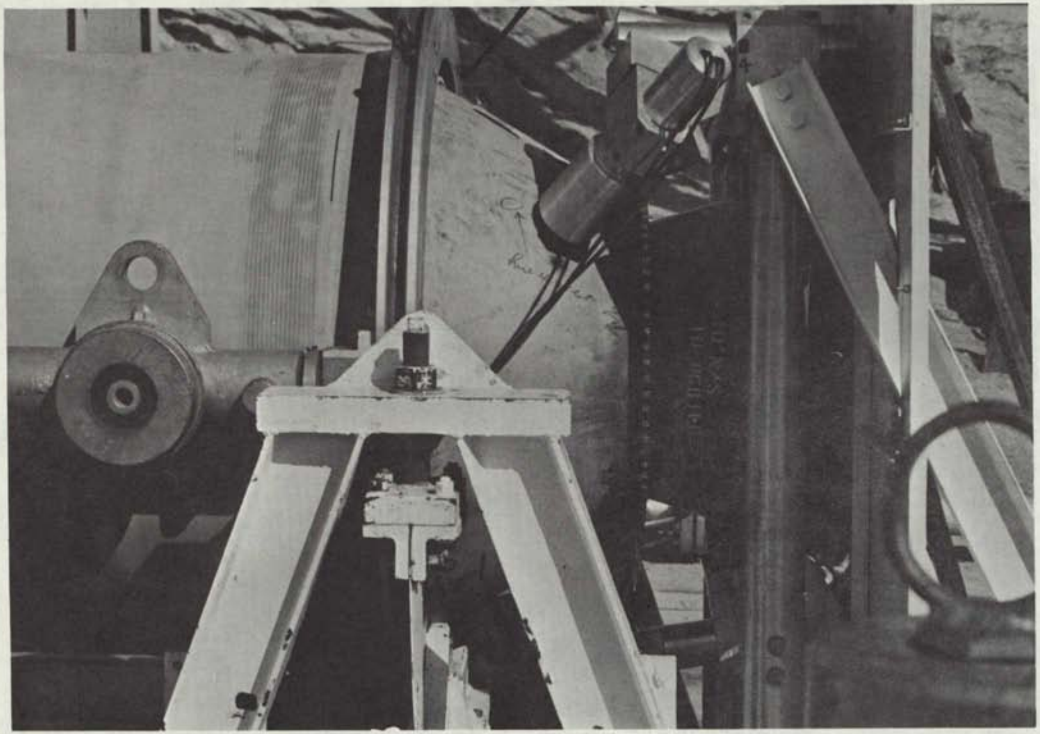


Figure 153. Subscale Motor and Test Stand

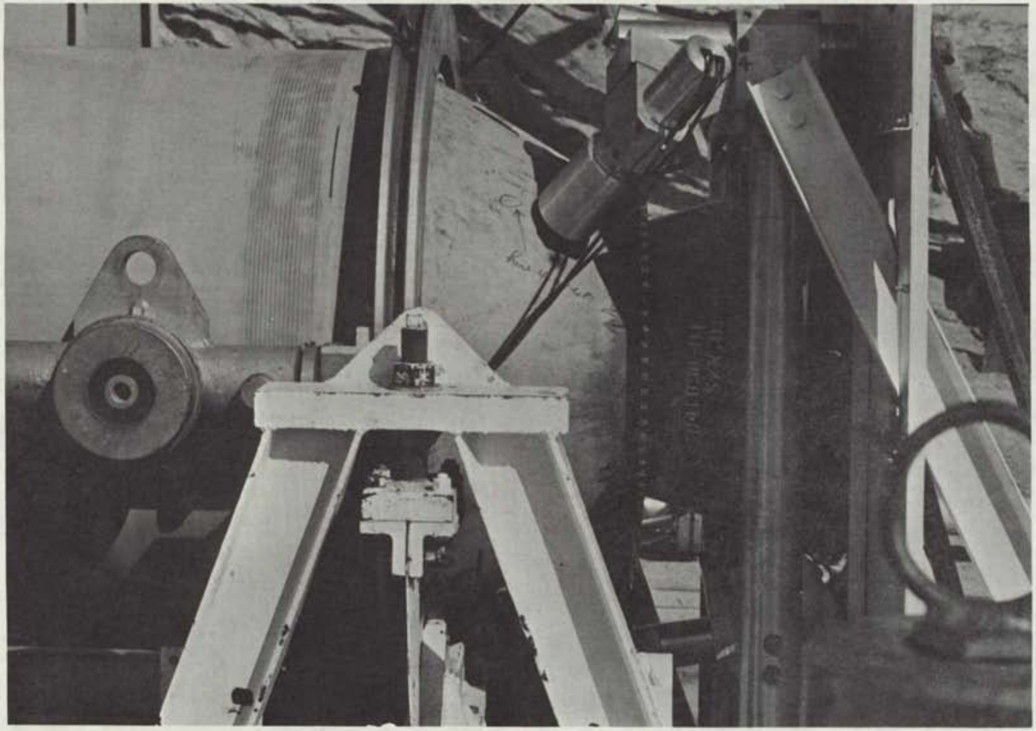


Figure 153. Subscale Motor and Test Stand

TABLE 42

SUBSCALE MOTOR PERFORMANCE

Motor No.	Nozzle Throat Material	Avg Web Pressure (psia)	Web Time (sec)
1	MX-4926 carbon[a]	471	56.8
2	LCCM-2626 graphite particle	466	57.5
3	SP-8050 carbon	476	56.2
4	SP-8030-96 silica	384	61.0
5	LCCM-2626 graphite particle segmented	446	58.4
6	SP-8057 carbon	446	58.3

[a]Standard base nozzle

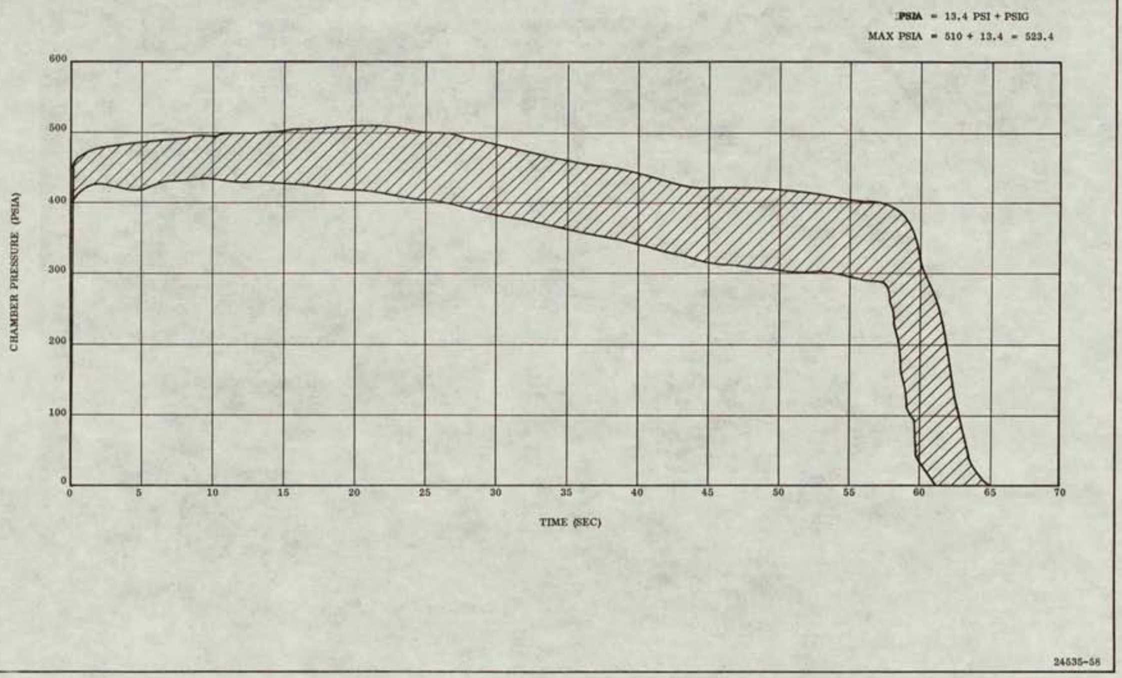


Figure 155. Pressure Time Envelope for Six Subscale Motor Firings

Figure 156. Subscale Nozzle No. 1 Submerged Liner and Nose

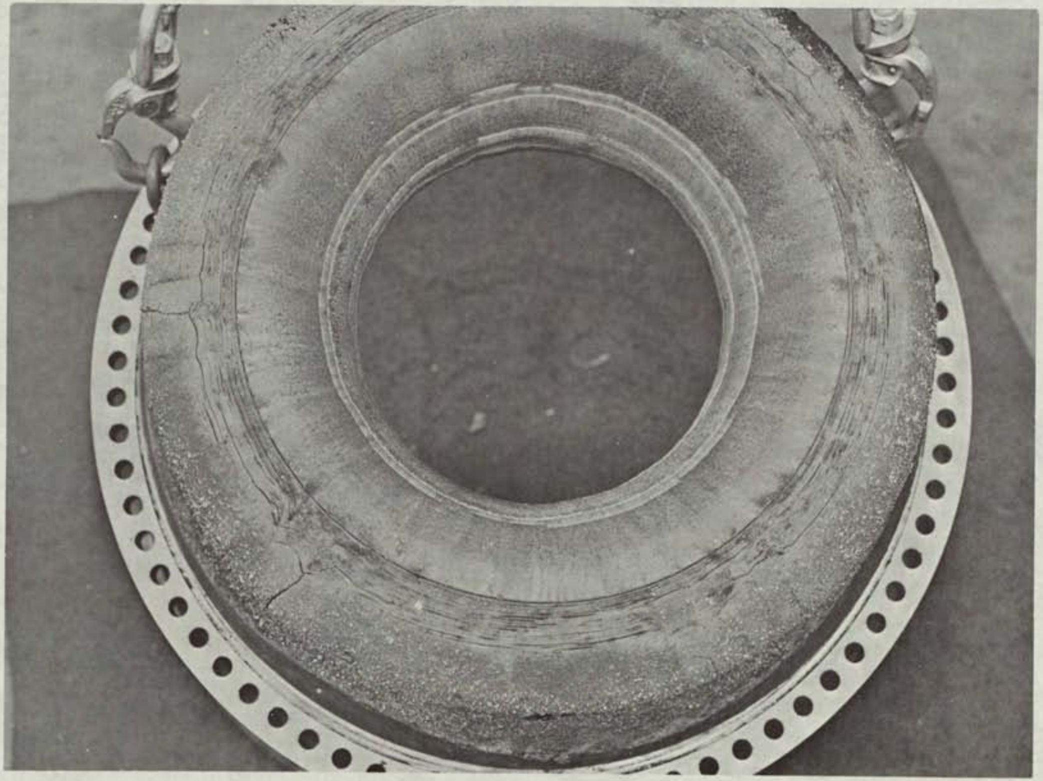


Figure 157. Subscale Nozzle No. 1 Nose, Inlet, and Throat

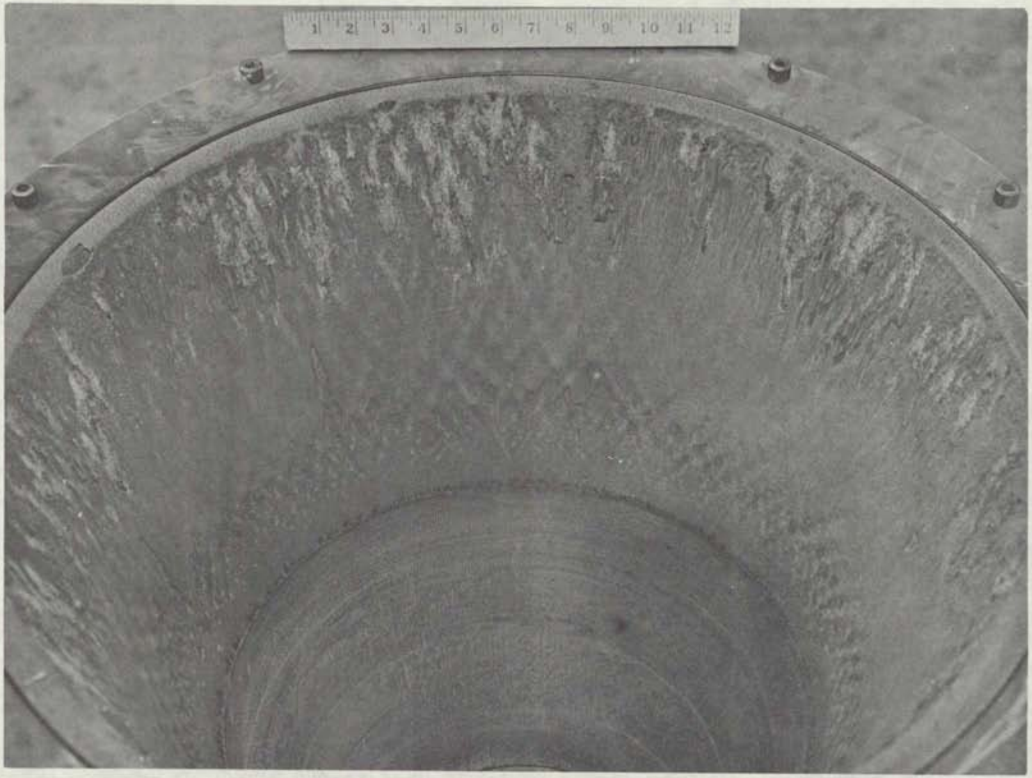


Figure 158. Subscale Nozzle No. 1 Exit Cone

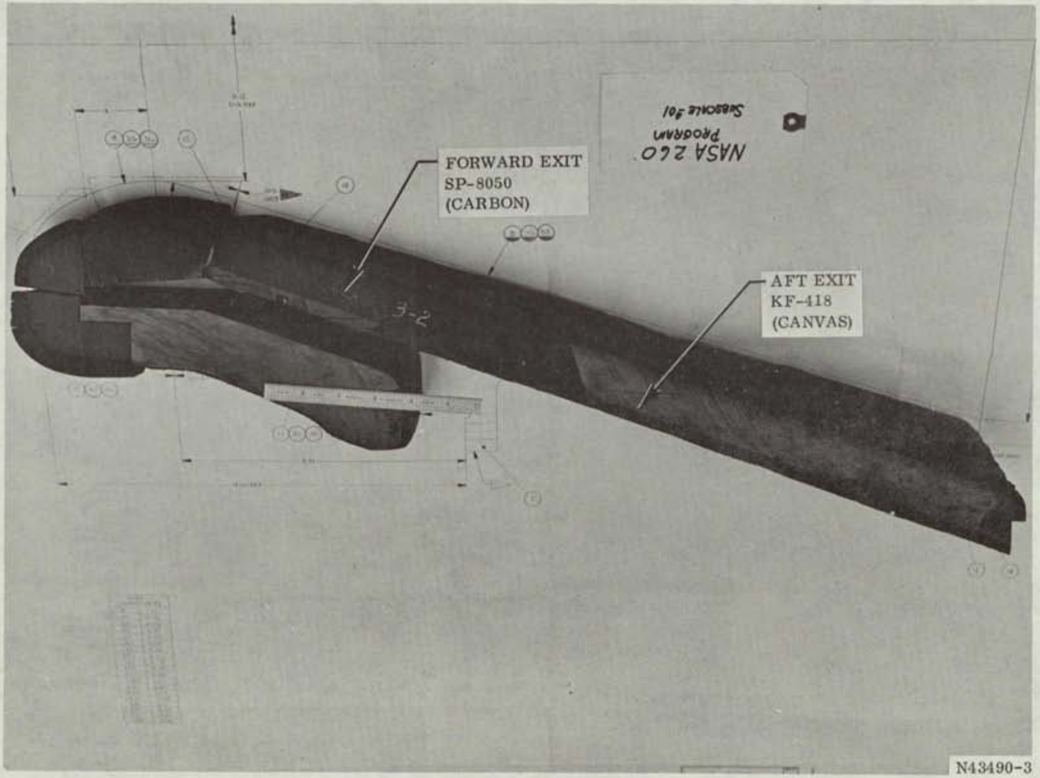


Figure 159. Nozzle No. 1 Sectioned at Propellant Star Valley

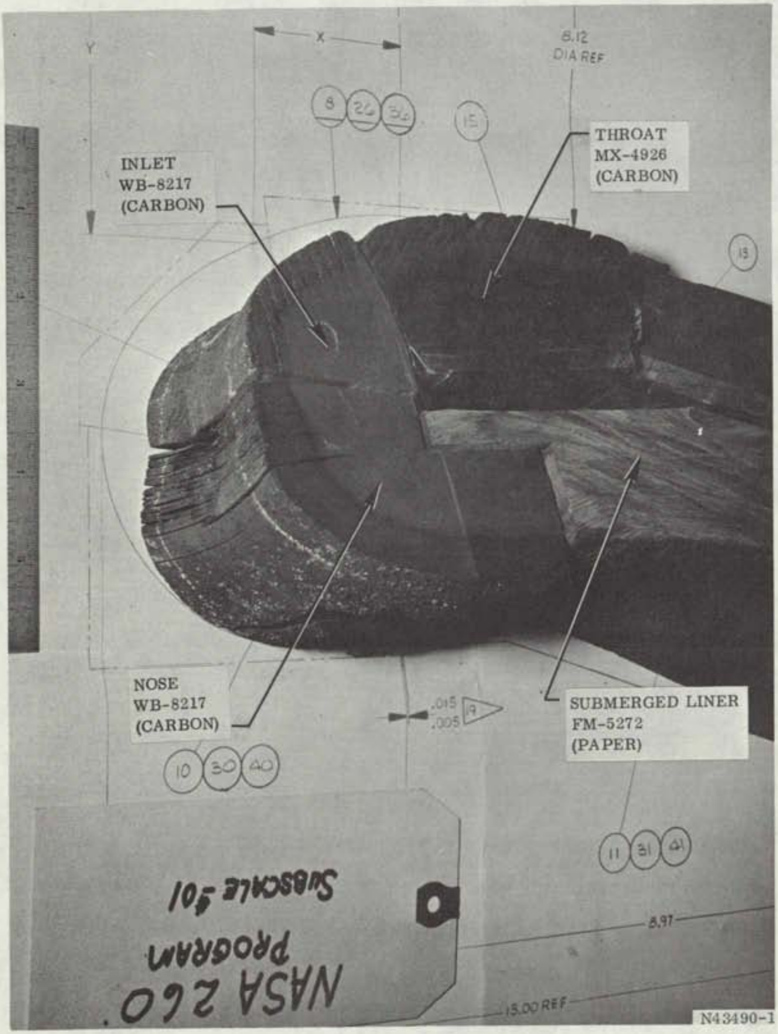
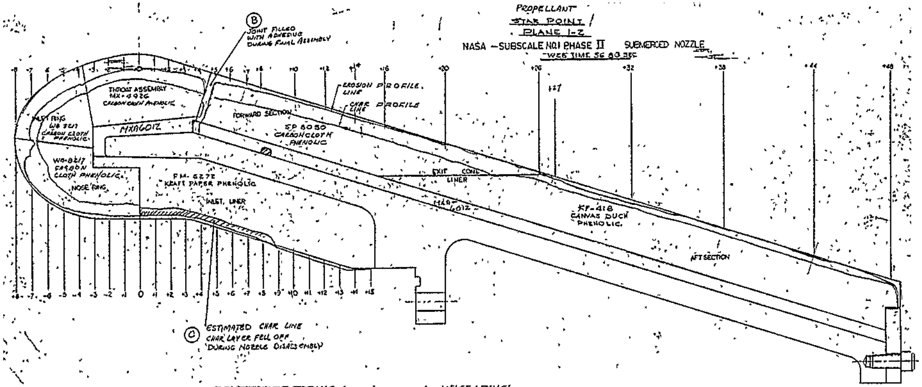


Figure 160. Nozzle No. 1 Submerged Liners Sectioned at Plane 2-3



INLET LINER

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
THROAT 0	0.08	1.40	0.36	6.33
+1	0.10	1.75	0.32	5.65
+2	0.11	1.93	0.34	5.98
+3	0.06	1.05	0.30	5.27
+4	0.10	1.75	0.28	4.92
+5	0.07	1.23	0.27	4.75
+6	0.06	1.05	0.24	4.22
+7	0.05	0.87	0.25	4.39
+8	0.00	0.00	0.25	4.39
+9	-0.07	-1.23	—	0.00
+10	-0.08	-1.41	—	0.00
+11	-0.09	-1.58	—	0.00
+12	-0.11	-1.93	—	0.00
+13	-0.12	-2.10	—	0.00
+14	-0.08	-1.41	—	0.00
+15	-0.05	-0.87	—	0.00

NOSE RING

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-8	0.55	9.67	0.76	13.19
-7	0.06	1.05	0.68	11.96
-6	0.09	1.58	0.60	10.55
-5	0.12	2.11	0.51	9.32
-4	0.11	1.93	0.49	8.62
-3	0.07	1.23	0.49	8.62
-2	0.07	1.23	0.48	8.79
-1	0.07	1.23	0.50	8.97
0	0.09	1.49	0.49	6.33

INLET RING

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-8	0.45	7.91	0.76	13.37
-7	0.47	8.27	0.77	13.54
-6	0.52	9.15	0.83	14.60
-5	0.54	9.50	0.86	15.13
-4	0.55	9.67	0.86	16.13

THROAT ASSEMBLY

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-3	0.51	8.97	0.83	14.25
-2	0.51	8.97	0.80	14.25
-1	0.49	8.62	0.82	14.42
0	0.46	8.09	0.82	14.07
+1	0.43	7.56	0.83	13.90
+2	0.33	5.80	0.79	13.37
+3	0.27	4.75	0.73	13.02
+4	0.23	4.04	0.73	13.02

EXIT CONE LINER

FORWARD SECTION

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+5	—	—	—	—
+6	0.20	3.51	0.73	12.51
+7	0.16	2.81	0.68	11.96
+8	0.14	2.46	0.63	10.90
+10	0.11	1.93	0.55	9.85
+12	0.09	1.58	0.52	9.32
+14	0.08	1.41	0.48	8.79
+16	0.07	1.23	0.48	8.44
+20	0.04	0.70	0.46	8.09
+24	0.00	0.00	0.28	4.92
+32				
+38				
+44				
+49				

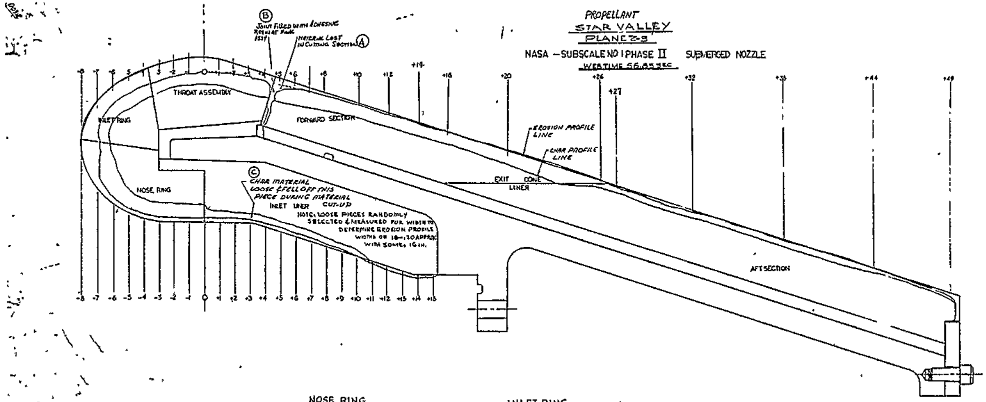
AFT SECTION

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+27	0.09	1.59	0.31	5.46
+32	0.10	1.75	0.25	4.39
+38	0.03	0.52	0.21	3.69
+44	0.02	0.35	0.24	4.22
+49	0.14	2.46	0.19	3.34

NOTES

1. MINUS SIGN (-) INDICATES WALL THICKNESS INCREASE
2. ADDED STATIONS +7, +14, +27 (EXIT CONE)
3. MATERIAL SURFACE OF INLET LINER LOST IN NOZZLE DISASSEMBLY Ⓒ
4. THROAT - FORWARD EXIT INTERFACE GAP FILLED WITH ADHESIVE IN FINAL NOZZLE ASSEMBLY Ⓑ

Figure 161. Nozzle No. 1 Erosion-Char Profile (Propellant Starpoint)



NOSE RING

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-8	0.60	10.55	0.96	16.89
-7	0.25	4.39	0.90	15.83
-6	0.16	2.81	0.70	12.31
-5	0.16	2.81	0.65	11.43
-4	0.16	2.81	0.62	10.90
-3	0.13	2.28	0.60	10.55
-2	0.14	2.46	0.60	10.55
-1	0.13	2.28	0.59	10.38
THROAT-0	0.15	2.63	0.58	10.20

INLET RING

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-8	0.55	9.67	0.93	16.36
-7	0.48	8.44	0.84	14.78
-6	0.48	8.44	0.90	15.83
-5	0.50	8.79	0.91	16.01
-4	0.48	8.44	0.88	15.48

INLET LINER

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
THROAT-0	0.15	2.63	0.43	7.55
+1	0.16	2.81	0.38	6.68
+2	0.14	2.46	0.34	5.98
+3	0.09	1.58	0.30	5.27
+4	0.12	2.11	0.34	5.98
+5	0.13	2.28	0.34	5.98
+6	0.11	1.93	0.33	5.98
+7	0.10	1.75	0.33	5.80
+8	0.05	0.87	0.28	4.92
+9	0.05	0.87	0.21	3.69
+10	0.00	0.00	0.15	2.63
+11	-0.12	-2.11	0.00	0.00
+12	-0.13	-2.28	0.00	0.00
+13	-0.12	-2.11	0.00	0.00
+14	-0.15	-2.63	0.00	0.00
+15	-0.07	-1.23	0.00	0.00

THROAT ASSEMBLY

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-3	0.52	9.15	0.84	14.78
-2	0.52	9.15	0.85	14.95
-1	0.50	8.79	0.88	15.48
0	0.45	7.91	0.88	15.48
+1	0.43	7.56	0.84	14.78
+2	0.31	5.45	0.80	14.07
+3	0.26	4.57	0.80	14.07
+4	0.22	3.87	0.78	13.72

EXIT CONE LINER

FORWARD SECTION

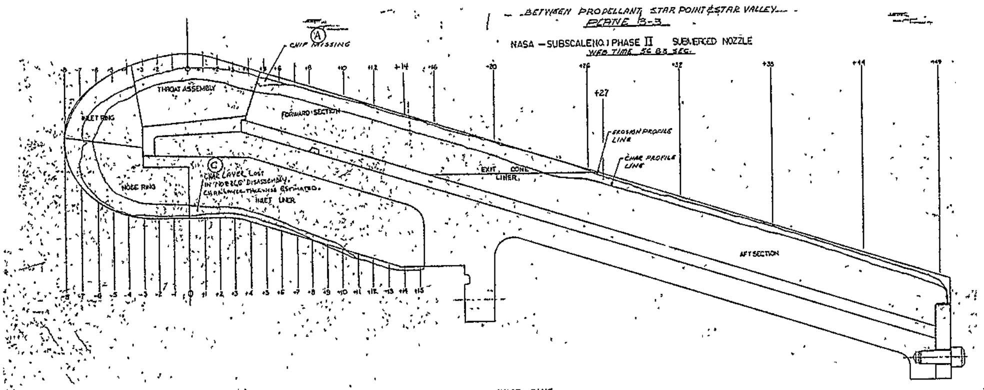
STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+5	—	—	—	—
+6	0.21	3.69	0.74	13.02
+7	0.12	2.11	0.66	11.60
+8	0.10	1.75	0.60	10.55
+10	0.04	0.80	0.48	8.44
+12	0.04	0.70	0.48	8.44
+14	0.04	0.70	0.44	7.74
+16	0.00	0.00	0.41	7.21
+20	-0.05	[illegible]	0.48	8.44
+26	-0.06	-1.05	0.22	3.87

AFT SECTION

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+27	0.04	0.70	0.22	[illegible]
+32	0.03	0.52	0.27	4.75
+38	0.05	0.87	0.21	[illegible]
+44	0.00	0.00	0.14	2.46
+49	0.15	2.63	0.23	4.39

NOTES

1. Minus (-) sign indicates increased wall thickness
2. Added stations +7, +14, +27 exit cone
3. Station +5, exit cone - not shown. Section lost in cutting Ⓐ
4. Throat - forward exit cone joint gap filled with adhesive resin at final assembly Ⓑ
5. Inlet liner char lost in nozzle disassembly and sectioning Ⓒ



NOSE RING

EROSION DEPTH	EROSION RATE MILS/SEC.	CHAR DEPTH	CHAR RATE MILS/SEC
0.50	8.79	0.90	15.83
0.14	2.46	0.75	13.19
0.08	1.40	0.64	11.26
0.08	1.40	0.56	9.85
0.05	0.87	0.52	9.15
0.10	1.75	0.48	8.44
0.05	0.87	0.45	7.91
0.09	1.58	0.45	7.91
0.12	2.10	0.48	8.40

INLET RING

EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
0.58	10.20	0.97	17.06
0.57	10.02	1.00	17.59
0.62	10.90	0.92	16.18
0.63	11.08	0.94	16.54
0.67	11.78	0.90	15.83

INLET LINER

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
THROAT 0	0.10	1.75	0.42	7.39
+1	0.15	2.63	0.37	6.51
+2	0.16	2.81	0.35	6.15
+3	0.14	2.46	0.34	5.98
+4	0.13	2.28	0.32	5.63
+5	0.15	2.63	0.33	5.80
+6	0.14	2.46	0.30	5.27
+7	0.11	1.93	0.23	4.04
+8	0.02	0.35	0.20	3.51
+9	-0.05	-0.87	0.22	3.87
+10	-0.11	-1.93	0.18	3.16
+11	-0.17	-2.99	0.05	0.87
+12	-0.16	-2.81	0.00	0.00
+13	-0.17	-2.99	0.00	0.00
+14	-0.14	-2.46	0.00	0.00
+15	-0.13	-2.28	0.00	0.00

THROAT ASSEMBLY

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
-3	0.53	9.32	0.85	14.95
-2	0.52	9.15	0.87	15.30
-1	0.50	8.79	0.88	15.48
0	0.46	8.09	0.85	14.95
+1	0.40	7.03	0.78	13.72
+2	0.30	5.27	0.72	12.66
+3	0.21	3.69	0.70	12.31
+4	0.17	2.99	0.70	12.31

EXIT CONE LINER

FORWARD SECTION

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+5	EST .18	EST 3.16	.68	11.96
+6	EST .14	EST 2.46	.54	9.50
+7	.12	2.12	.52	9.15
+8	.13	2.28	.51	8.97
+10	.08	1.40	.50	8.79
+12	.08	1.40	.47	8.27
+14	.05	0.87	.47	8.27
+16	.05	.87	.45	7.91
+20	.03	.52	.45	7.91
+26	-.02	0.35	.33	5.80

AFT SECTION

STATION	EROSION DEPTH	EROSION RATE MILS/SEC	CHAR DEPTH	CHAR RATE MILS/SEC
+27	0.08	1.40	0.32	5.63
+32	0.06	1.05	0.29	5.10
+38	0.05	0.87	0.26	4.57
+44	0.08	1.40	0.28	4.92
+49	0.13	2.28	0.33	5.80

NOTES:

1. MINUS (−) SIGN INDICATES INCREASED WALL THICKNESS
2. ADDED STATIONS +7, +14, +27 (EXIT CONE)
3. NOZZLE MATERIAL SURFACE LOST IN INLET LINER © AND FORWARD EXIT CONE Ⓐ.

Figure 163. Nozzle No. 1 Erosion-Char Profile Between Propellant Starpoint and Star Valley

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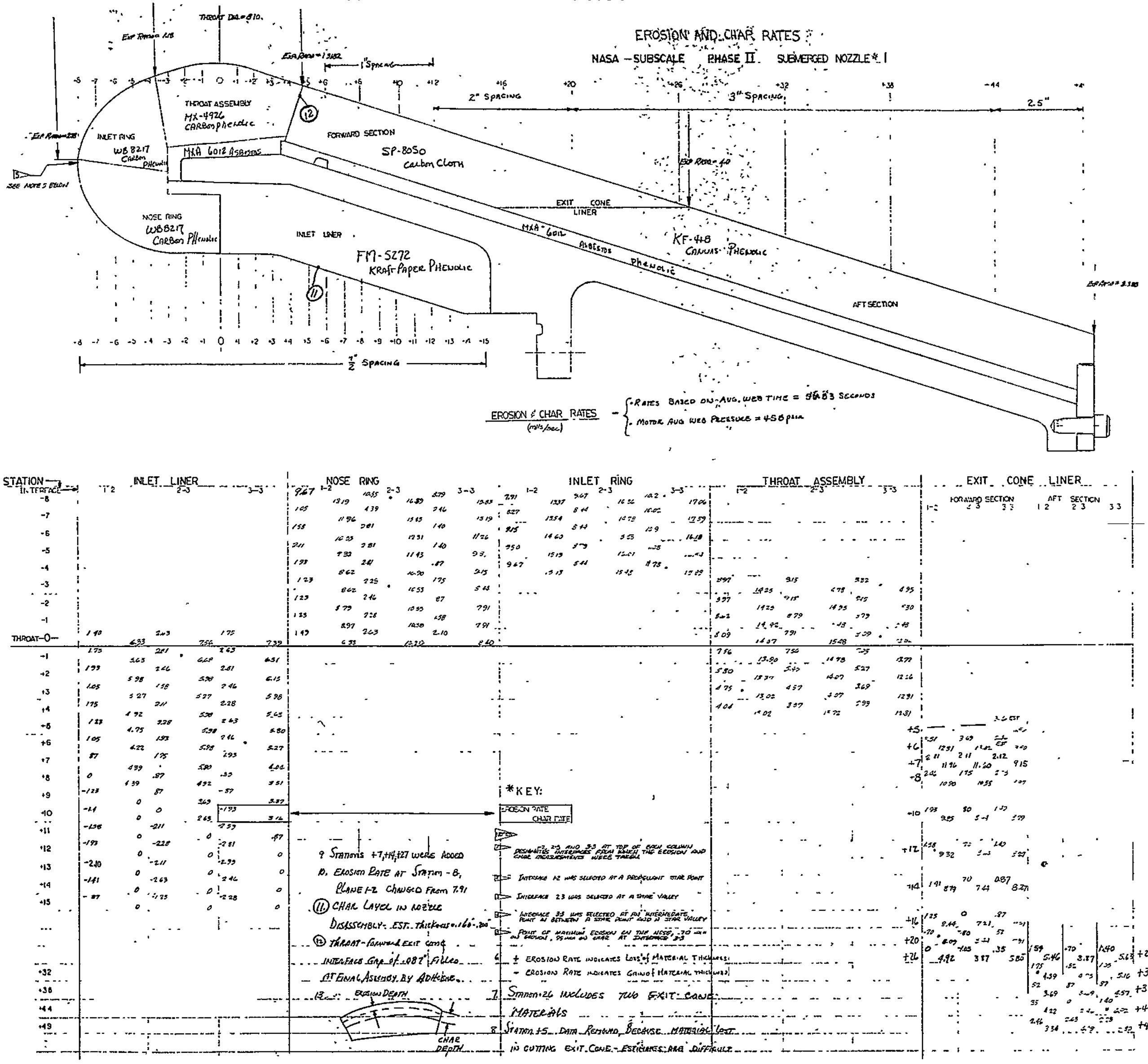


Figure 164. Nozzle No. 1 Three Plane Erosion-Char Summary

TABLE 43

NOZZLE NO. 1 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged Liner FM-5272 paper	Ply delaminations Low uniform erosion Very weak char layer Good performance
Nose WB-8217 carbon	Local spalling and cracks Local gouging and ply delaminations Low uniform erosion Good performance
Inlet WB-8217 carbon	Ply delaminations Low uniform erosion Light surface spall Excellent performance
Throat MX-4926 carbon	Ply delaminations Low uniform erosion Excellent performance
Forward exit SP-8050	Ply delaminations Low uniform erosion Excellent performance
Aft exit KF-418 canvas	Weak char layer Ply delaminations Small local gouging Very good performance

Insulation Liner	Comments
Exit Cone Insulation MXA-6012 asbestos	Local ply delaminations Satisfactory performance
Inlet - Throat Insulation MXA-6012 asbestos	Local ply delaminations Satisfactory performance

Figure 165. Subscale Nozzle No. 2 Submerged Liner and Nose

Figure 166. Subscale Nozzle No. 2 Nose, Inlet, and Throat

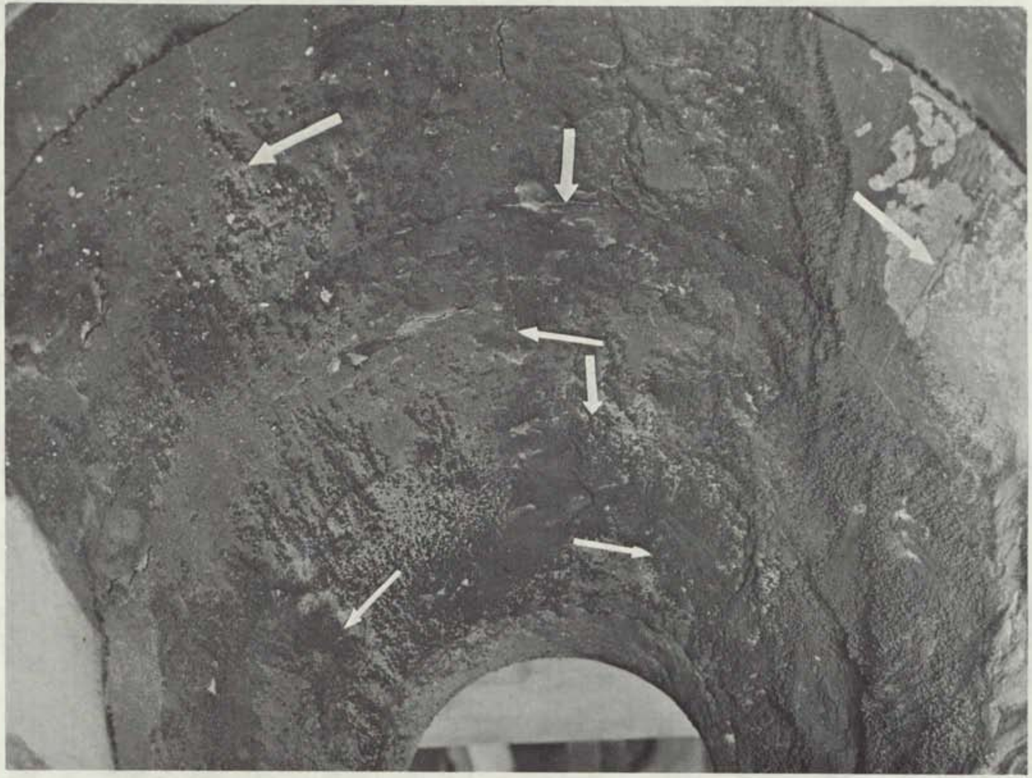


Figure 167. Subscale Nozzle No. 2 Exit Cone

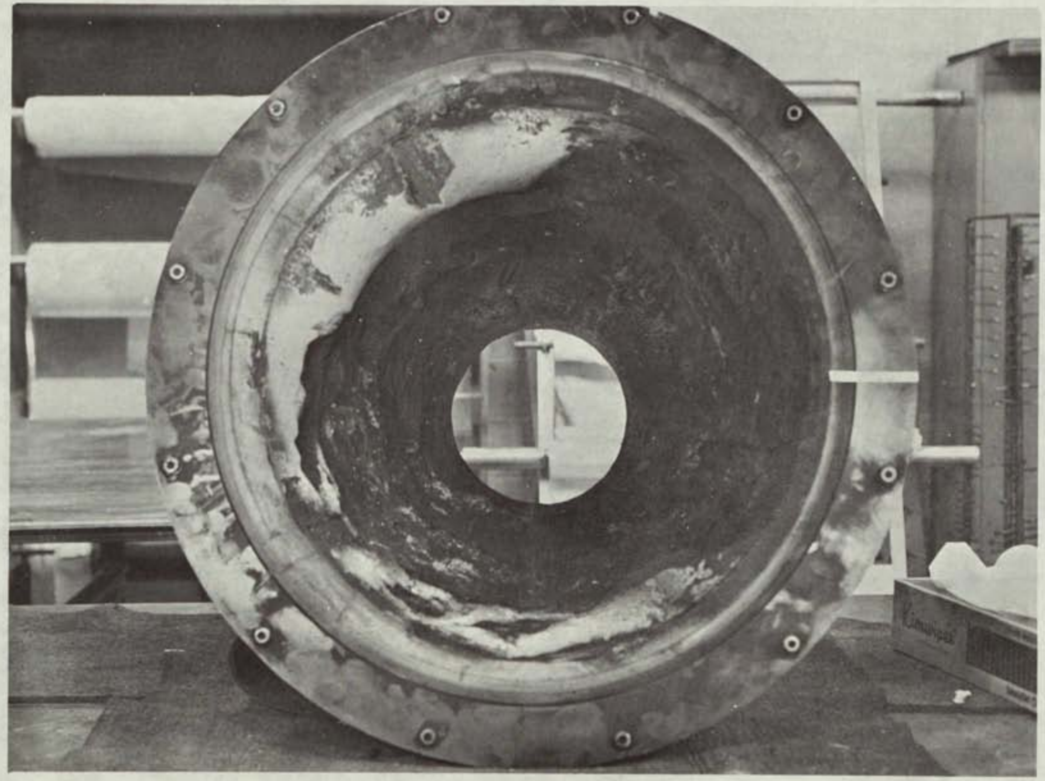


Figure 168. Subscale Nozzle No. 2 Aft Exit Cone

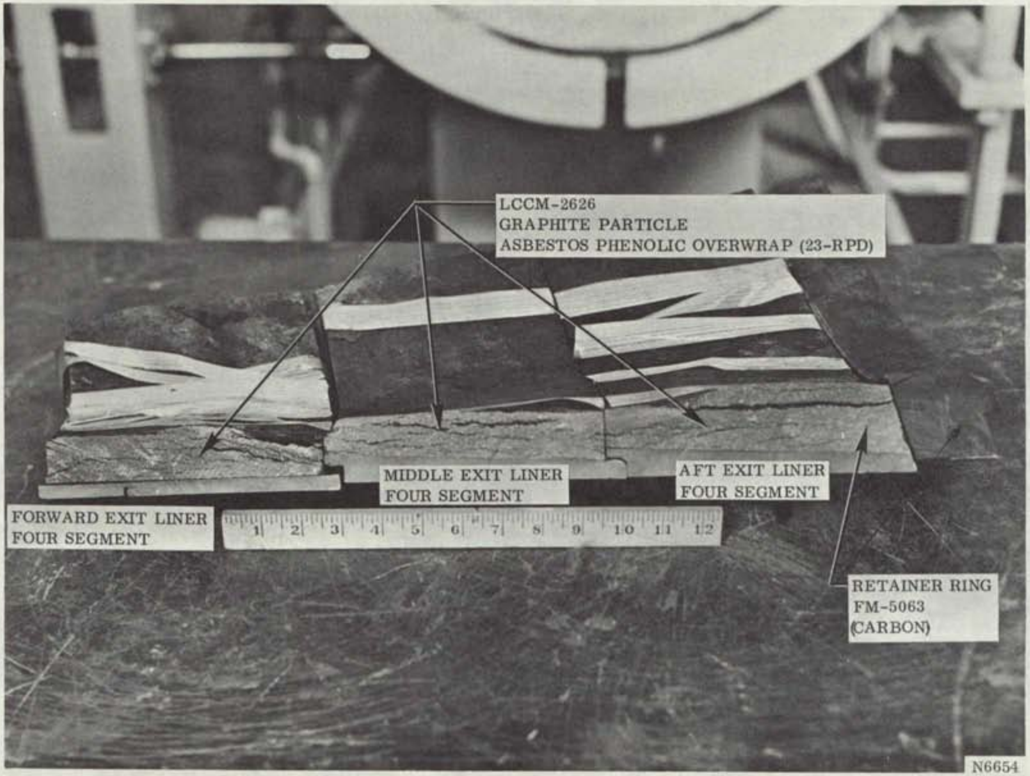


Figure 169. Sectioned Nozzle No. 2 Exit Cone

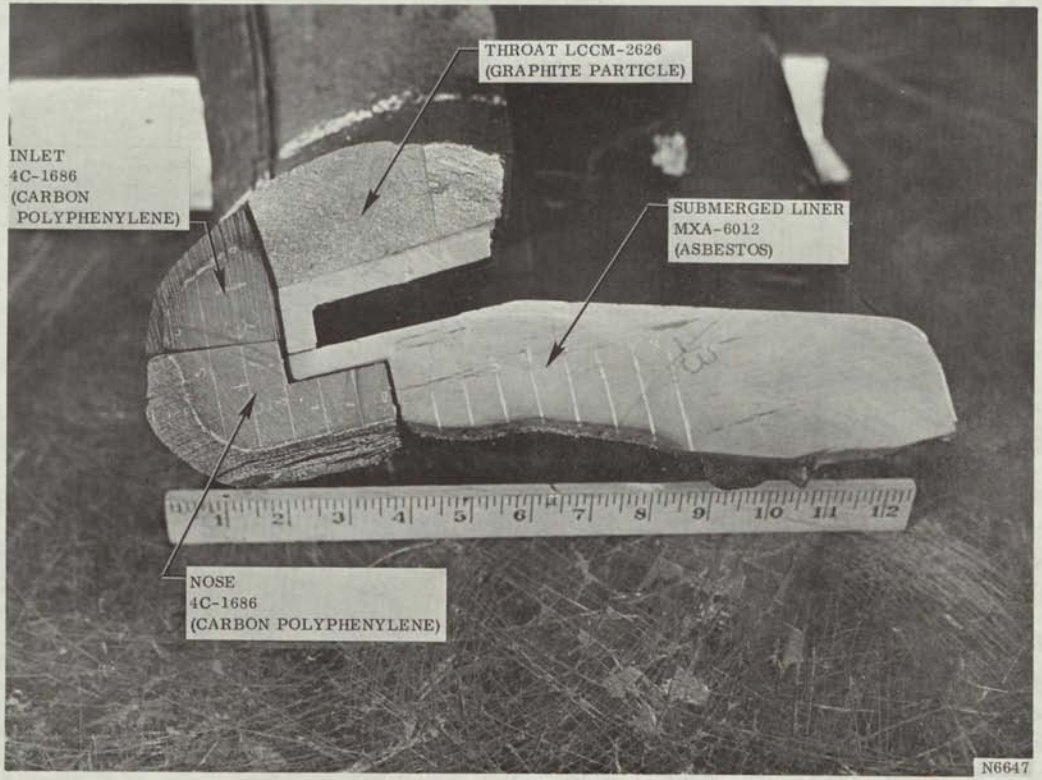
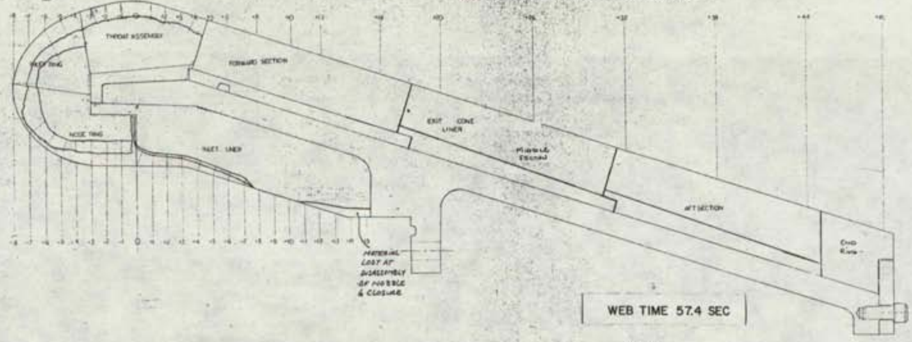


Figure 170. Sectioned Nozzle No. 2 Submerged Liners

PLANT ... STAR POINT

NASA – SUBSCALE #2 PHASE II . SUBMERGED NOZZLE



WEB TIME 57.4 SEC

STATION	INLET LINER		NOSE RING		INLET RING		T-2626 THROAT ASSEMBLY		EXIT CONE LINER FORWARD SECTION	EXIT CONE LINER AFT SECTION
-8			0.28 (4.61)	0.88 (15.48)	0.45 (7.83)	0.79 (13.74)				
-7			0.12 (2.09)	0.66 (11.48)	0.40 (6.96)	0.75 (13.05)				
-6			0.15 (2.61)	0.58 (10.09)	0.50 (8.70)	0.90 (15.66)				
-5			0.26 (4.52)	0.60 (10.44)	0.55 (9.57)	1.02 (17.74)				
-4			0.38 (6.63)	0.70 (12.18)	0.57 (9.92)	1.12 (19.50)				
-3			0.40 (6.96)	0.83 (14.44)			.51 (8.87)	① -3		
-2			0.41 (7.15)	0.81 (14.09)			.52 (9.04)	-2		
-1			0.42 (7.30)	0.88 (15.30)			.54 (9.39)	-1		
THROAT-0	0.51 (8.87)	0.58 (10.09)					.50 (8.70)	0		
+1	0.35 (6.09)	0.42 (7.30)					.48 (8.35)	+1		
+2	0.31 (5.39)	0.40 (6.96)					.53 (9.22)	+2		
+3	0.27 (4.69)	0.38 (6.61)					.40 (6.96)	+3		
+4	0.21 (3.65)	0.34 (5.91)					.45 (7.83)	+4		
+5	0.20 (3.48)	0.30 (5.22)								
+6	0.18 (3.13)	0.23 (4.00)								
+7	0.09 (1.56)	0.23 (4.00)								
+8	—	—								
+9	—	—								
+10	—	—								
+11	INITIAL MATERIAL SURFACE LOST IN DISASSEMBLY									
+12										
+13										
+14										
+15										
+16										
+20										
+26										
+30										
+33										
+44										
+49										

NOTES:-

① NO CHAR DEPTH OR RATE SHOWN FOR T-2626 MATERIAL. CHAR COULD NOT BE SEEN WITH EYE OBSERVATION.

2. | EROSION DEPTH (EROSION RATE) / CHAR DEPTH (CHAR RATE) |

3. ADDED STATION +8 THRU +15 (INLET LINER) -4 CHAR (INLET RING)

Total Depth

Fig. ...

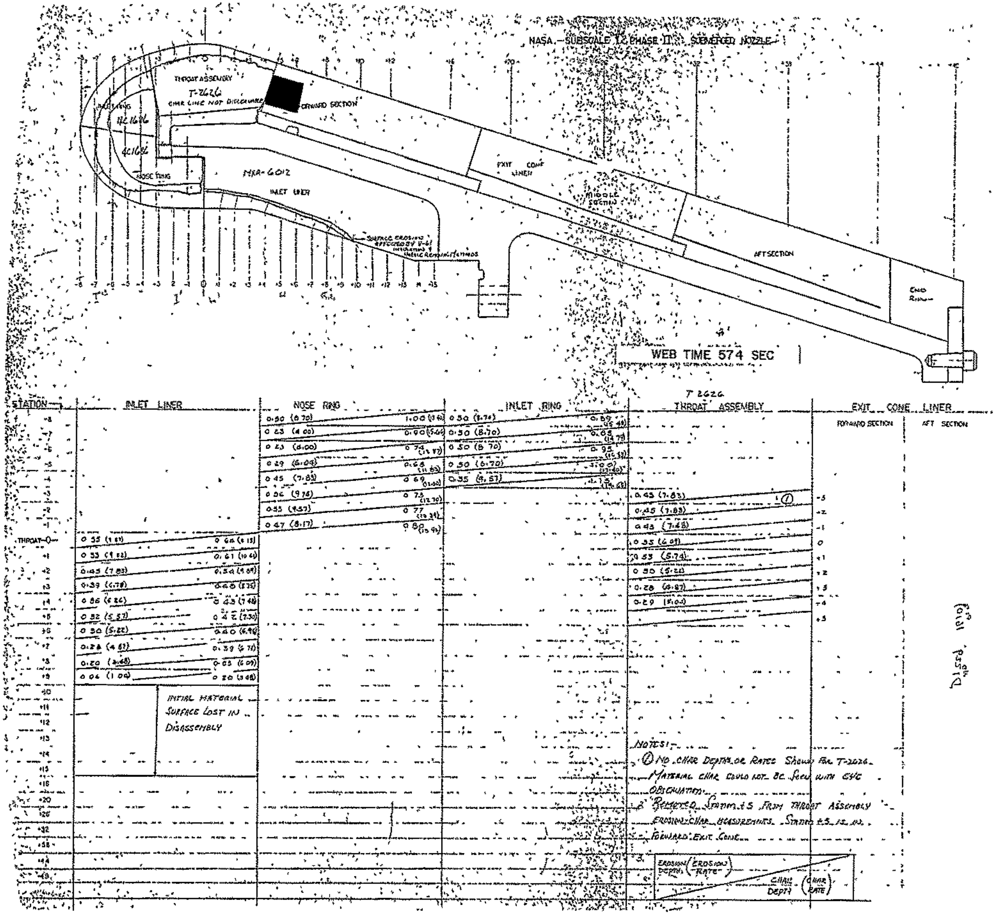
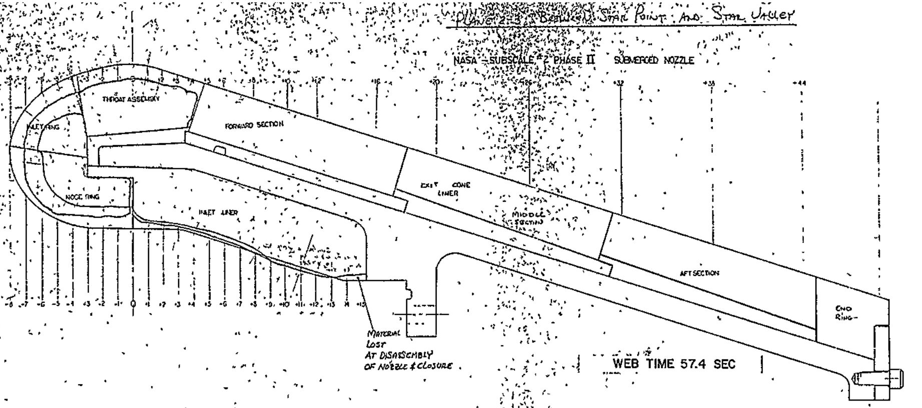


Figure 172. Nozzle No. 2 Erosion-Char Profile (Propellant Star Valley)



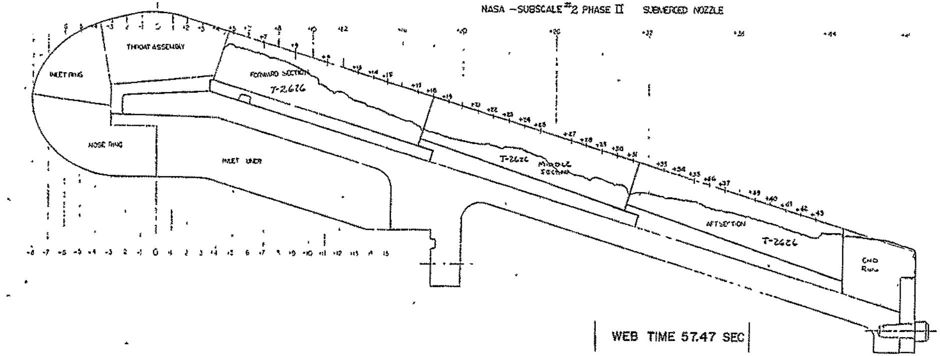
T-2626

STATION	INLET LINER	NOSE RING	INLET RING	THROAT ASSEMBLY	EXIT CONE LINER FORWARD SECTION	EXIT CONE LINER AFT SECTION
-8		0.47 (8.17) / 1.08 (18.77)	0.47 (8.17) / 0.94 (16.35)			
-7		0.22 (3.83) / 0.82 (14.24)	0.40 (6.96) / 0.87 (15.14)			
-6		0.17 (2.95) / 0.70 (12.18)	0.48 (8.35) / 1.00 (17.40)			
-5		0.15 (2.61) / 0.65 (11.31)	0.51 (8.87) / 1.10 (19.14)			
-4		0.33 (5.74) / 0.66 (11.48)	0.55 (9.57) / 1.30 (22.61)			
-3		0.39 (6.78) / 0.70 (12.18)		0.48 (8.35) (1)		
-2		0.38 (6.61) / 0.69 (12.00)		0.50 (8.70)		
-1		0.38 (6.61) / 0.71 (12.35)		0.53 (9.22)		
THROAT 0	0.30 (5.22) / 0.42 (7.30)			0.49 (8.52)		
+1	0.20 (3.48) / 0.28 (4.87)			0.48 (8.35)		
+2	0.12 (2.08) / 0.23 (4.00)			0.45 (7.83)		
+3	0.10 (1.74) / 0.18 (3.13)			0.39 (6.78)		
+4	0.08 (1.39) / 0.24 (4.17)			0.42 (7.30)		
+5	0.09 (1.56) / 0.23 (4.00)					
+6	0.08 (1.39) / 0.22 (3.83)					
+7	0.06 (1.04) / 0.18 (3.13)					
+8	-0.03 (0.52) / 0.13 (2.26)					
+9	-0.09 (1.56) / —					
+10	-0.10 (1.74) / —					
+11	-0.10 (1.74) / —					
+12	-0.09 (1.56) / —					
+13	— / —					
+14	INITIAL MATERIAL SURFACE LOST AT NOZZLE DISASSEMBLY					
+15						
+16						
+20						
+26						
+32						
+38						
+44						
+50						

NOTES -

1. NO CHAR DEPTH OR RATE SHOWN FOR T-2626. MATERIAL CHAR COULDN'T BE SEEN WITH EYE OBSERVATION.
2. EROSION DEPTH (EROSION RATE) / CHAR DEPTH (CHAR RATE)
3. ADDED STATIONS +14, +15.

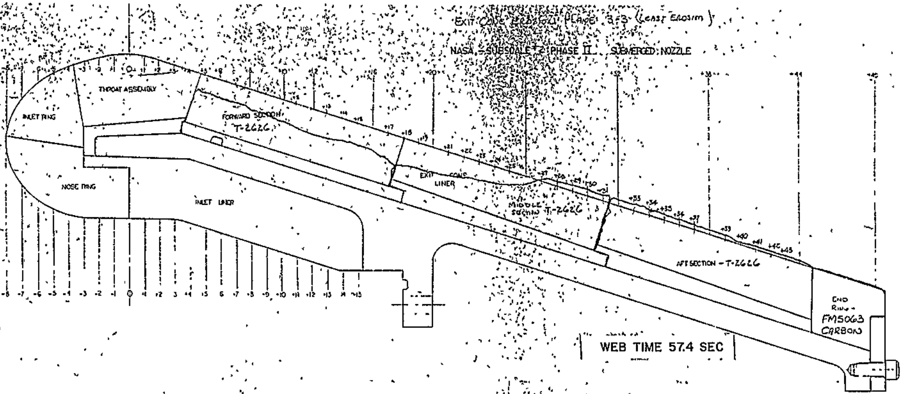
Figure 173. Nozzle No. 2 Erosion-Char Profile (Between Propellant Starpoint and Star Valley)



STATION	INLET LINER	NOSE RING	INLET RING	THROAT ASSEMBLY	EXIT CONE LINER FORWARD SECTION Erosion Depth	Erosion Rate	MIDDLE SECTION Erosion Depth	Erosion Rate	AFT SECTION END RING Erosion Depth	Erosion Rate
-8										
-7										
-6										
-5										
-4										
-3										
-2										
-1										
THROAT-0										
+1										
+2										
+3										
+4										
+5					.44	11.3				
+6					.40	6.9				
+7					.40	6.9				
+8					.38	6.6				
+9					.41	7.1				
+10					.56	9.0				
+11					.75	13.0				
+12					.83	15.6				
+13					.83	14.8				
+14					.90	15.6				
+15					.92	16.0				
+16					.97	16.8				
+20							1.12	19.5		
+26							0.90	15.6		
+27							1.07	18.6		
+32									.93	16.2
+38									.62	10.7
+44									.32	5.6
+49									-.06	-1.05

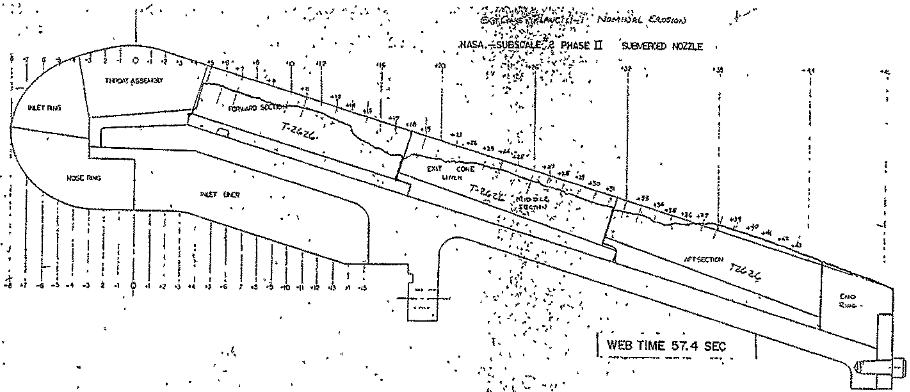
NOTE (1) NO CHAR DEPTHS OR RATES ARE SHOWN. MATERIAL CHAR COULD NOT BE SEEN WITH EYE OBSERVATION
2. ADDED STATIONS +27 & +49
3. MINUS (-) SIGN INDICATES AN INCREASED WALL THICKNESS.

Figure 174. Nozzle No. 2 Maximum Exit Erosion



STATION	INLET LINER	NOSE RING	INLET RING	THROAT ASSEMBLY	EXIT CONE LINER FORWARD SECTION (2) EROSION DEPTH	EROSION RATE	MIDDLE SECTION (2) EROSION DEPTH	EROSION RATE	AFT SECTION END RING (2) EROSION DEPTH	EROSION RATE
-8										
-7										
-6										
-5										
-4										
-3										
-2										
-1										
THROAT-0										
+1										
+2										
+3										
+4										
+5					0.62	10.8				
+6					0.57	9.9				
+7					0.58	10.1				
+8					0.53	9.2				
+9					0.66	11.5				
+10					0.70	12.2				
+11					0.71	12.8				
+12					0.78	13.5				
+13					0.79	13.7				
+14					0.77	13.4				
+15					0.68	11.8				
+16					0.64	11.8				
+20							0.82	14.3		
+26							0.50	5.2		
+27							-0.07	-1.22		
+32									-0.19	-3.3
+38									-0.14	-2.4
+44									-0.09	[illegible]
+49									-0.03	-0.5

Notes.
1. Added Stations +27 and +49
(2) No char depths or rates shown for T-2626 material char could not be seen with eye observations.
3. Minus (-) sign indicates increased wall thickness.



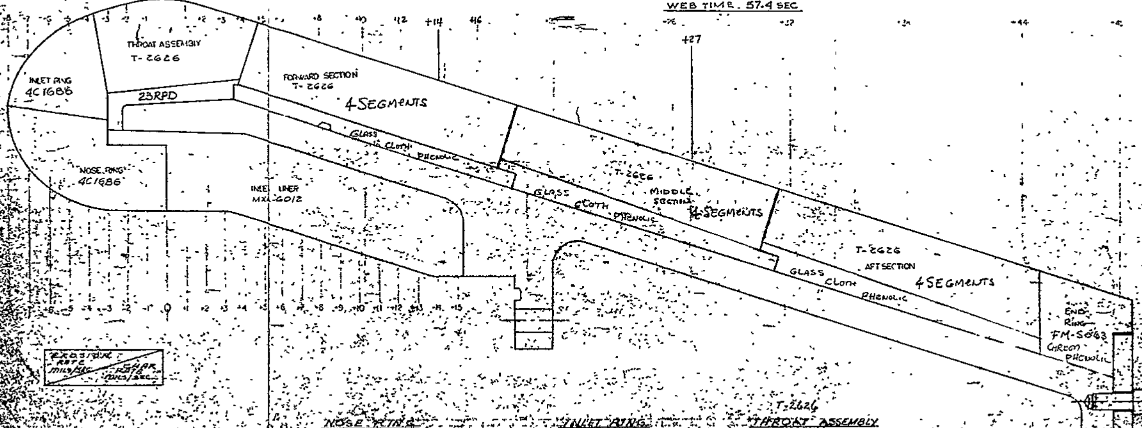
STATION	INLET LINER	NOSE RING	INLET RING	THROAT ASSEMBLY	EXIT CONE LINER: FORWARD SECTION (1) Erosion Depth	Erosion Rate	MIDDLE SECTION (1) Erosion Depth	Erosion Rate	AFT SECTION (1) Erosion Depth	Erosion Rate
+5					0.40	10.4				
+6					0.49	8.5				
+7					0.35	9.2				
+8					0.54	9.4				
+9					0.57	9.9				
+10					0.49	8.5				
+11					0.53	6.1				
+12					0.35	5.7				
+13					0.39	6.8				
+14					0.45	7.5				
+15					0.70	13.6				
+16					0.84	14.9				
+20							0.62	10.8		
+26							0.33	5.7		
+27							0.38	6.60		
+32									0.38	6.60
+38									-0.17	-2.9
+44									-0.14	-2.4
+49									-0.03	-0.52

NOTES:
(1) NO CHAR DEPTHS OR RATES SHOWN. MATERIAL CHAR COULD NOT BE SEEN WITH EYE OBSERVATIONS
2. ADDED STATIONS +27 & +29
3. MINUS (-) SIGN INDICATES MATERIAL WALL THICKNESS INCREASE

Figure 176. Nozzle No. 2 Nominal Exit Erosion

SUMMARY
EROSION AND CHAR RATES

NASA – SUBSCALE NOZ PHASE II . SUBMERGED NOZZLE
WEB TIME . 57.4 SEC



T-2626

Station	NOSE RING Plane 1-2 Erosion Rate	Char Rate	Plane 1-3 Erosion Rate	Char Rate	Plane 2-3 Erosion Rate	Char Rate	INLET RING Plane 1-2 Erosion Rate	Char Rate	Plane 1-3 Erosion Rate	Char Rate	Plane 2-3 Erosion Rate	Char Rate	THROAT ASSEMBLY Plane 1-2 Erosion Rate	Char Rate	Plane 1-3 Erosion Rate	Char Rate	Plane 2-3 Erosion Rate	Char Rate
	8.70	17.40	6.61	15.48	8.17	18.79	8.70	15.48	7.83	13.74	8.17	16.35						
	4.00	15.66	2.08	11.48	3.83	14.26	8.70	14.79	6.96	13.05	6.96	15.14						
	4.00	12.87	2.61	10.09	2.95	12.18	8.70	16.53	8.70	15.66	8.35	17.40						
	5.04	11.83	4.52	10.44	2.61	11.31	8.70	17.40	[illegible]	17.74	8.87	10.14						
	7.83	12.00	6.61	12.18	5.74	11.48	9.57	19.66	9.92	19.50	9.57	22.62						
	9.74	12.70	6.96	14.44	6.78	12.18							7.83	—	8.87	—	9.35	—
-2	9.57	13.39	7.13	14.09	6.61	12.00							7.83	—	9.04	—	8.70	—
-1	8.17	13.92	7.30	14.26	6.61	12.35							7.48	—	7.92	—	[illegible]	—
0													6.09	—	8.70	—	3.52	—
+1													5.74	—	8.35	—	6.35	—
+2													5.22	—	9.22	—	7.33	—
+3													4.57	—	6.96	—	6.78	—
+4													5.04	—	7.83	—	7.50	—

INLET LINER

Station	Plane 1-2 Erosion Rate	Char Rate	Plane 1-3 Erosion Rate	Char Rate	Plane 2-3 Erosion Rate	Char Rate
THROAT 0	9.57	11.13	8.87	10.09	5.22	7.30
+1	9.22	10.61	6.09	7.30	3.48	4.87
+2	7.83	9.39	5.39	6.96	2.08	4.00
+3	6.78	8.35	4.69	6.61	1.74	3.13
+4	6.26	7.48	3.65	5.31	1.39	4.17
+5	5.57	7.30	3.48	5.22	1.56	4.00
+6	5.22	6.96	2.61	4.35	1.39	3.83
+7	4.87	6.78	1.56	3.83	1.04	3.13
+8	3.48	5.09	—	—	-0.52	2.26
+9	1.04	3.48	—	—	-1.56	—
+10				—	-1.74	—
+11					-1.74	—
+12					-1.56	—
+13					—	—
+14						
+15						

INITIAL MATERIAL SURFACE LOST IN DISASSEMBLY OF NOZZLE CLOSURE

INITIAL MATERIAL SURFACE LOST IN DISASSEMBLY OF NOZZLE-CLOSURE

INITIAL MATERIAL SURFACE LOST IN DISASSEMBLY OF NOZZLE-CLOSURE

EXIT CONE LINER

T-2626

FORWARD SECTION — MIDDLE SECTION

Station	Erosion Rate	Char Rate	Erosion Rate	Char Rate	Erosion Rate	Char Rate
+5	11.30	—	10.80	—	10.40	—
+6	3.90	—	9.90	—	8.50	—
+7	6.90	—	10.10	—	9.20	—
+8	5.60	—	9.20	—	9.[illegible]	—
+9	7.10	—	11.50	—	9.3[illegible]	—
+1[illegible]	9.09	—	12.20	—	8.50	—
+1[illegible]	15.50	—	13.50	—	5.70	—
+14	15.60	—	13.40	—	7.50	—
+1[illegible]	16.80	—	11.80	—	14.10	—

T-2626

Station	Erosion Rate	Char Rate	Erosion Rate	Char Rate	Erosion Rate	Char Rate
+20	19.50	—	14.30	—	[illegible]	—
+26	15.60	—	5.20	—	5.70	—

Station	Erosion Rate	Char Rate	Erosion Rate	Char Rate	Erosion Rate	Char Rate	MAXIMUM	MINIMUM	AVERAGE
+27	18.6	—	4.22	—	[illegible]	—			
+32	—	—	—	—	—	—	15.20	-3.37	-.69
+38	—	—	—	—	—	—	10.70	-2.40	-.33
+44	—	—	—	—	—	—	5.60	-1.59	-3.99
+49	—	—	—	—	—	—	-1.05	[illegible]	.52

T-2626

FM

5. EROSION DEPTH
CHAR DEPTH

6. ADDED STATIONS +8 THRU +15 (INLET LINER)

NOTES:

1. MINUS (-) SIGN INDICATES AN INCREASE IN MATERIAL THICKNESS
2. NO CHAR DEPTHS OR RATES SHOWN FOR T-2626. MATERIAL CHAR COULD NOT BE SEEN WITH EYE OBSERVATION
3. ADDED STATIONS +27 & +29 (EXIT CONE)
4. INLET-THROAT PLANE IDENTIFICATION
   - PLANE 1-2 ~ PROPELLANT STAR VALLEY
   - PLANE 1-3 ~ PROPELLANT STAR POINT
   - PLANE 2-3 ~ INBETWEEN PROPELLANT STAR VALLEY AND STAR POINT

Figure 177. Nozzle No. 2 Three Plane Erosion-Char Rate Summary

TABLE 44

NOZZLE NO. 2 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged MXA-6012 asbestos	Ply delaminations Uniform erosion Good performance
Nose 4C-1686 carbon polyphenylene	Ply delaminations Uniform erosion Local gouging Good performance
Inlet 4C-1686 carbon polyphenylene	Ply delaminations Uniform erosion Good performance
Throat LCCM-2626 graphite particle phenolic	Uniform erosion Local spalling Internal delaminations Very good performance
Forward Exit LCCM-2626X graphite particle phenolic segmented	Nonuniform erosion Spalled and gouged areas Internal delamination Segmented joint O.K. Fair performance
Middle Exit LCCM-2626X graphite particle phenolic segmented	Spalled and gouged area Nonuniform erosion Internal delaminations Segmented joints O.K. Fair performance
Aft Exit LCCM-2626X graphite particle phenolic segmented	Spalled and gouged areas Nonuniform erosion Internal delaminations Segmented joints O.K. Fair performance

Insulation Liner	Comments
Exit Cone Insulation 1581 glass phenolic	No delaminations Very satisfactory performance
Inlet-Throat Insulation 23-RPD asbestos phenolic	No delaminations Very satisfactory performance

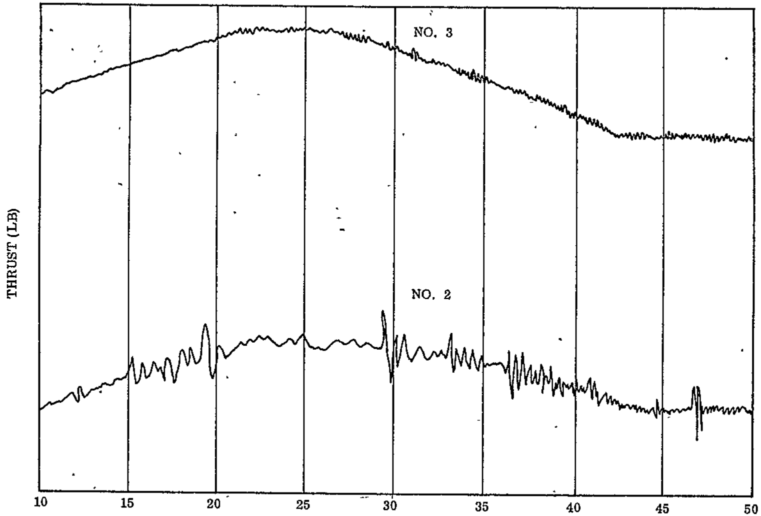


Figure 178. Partial Motor Thrust vs Time, Nozzles No. 2 and 3

Figure 179. Nozzle No. 3 Submerged Liner and Nose

Figure 180. Nozzle No. 3 Nose, Inlet, and Throat

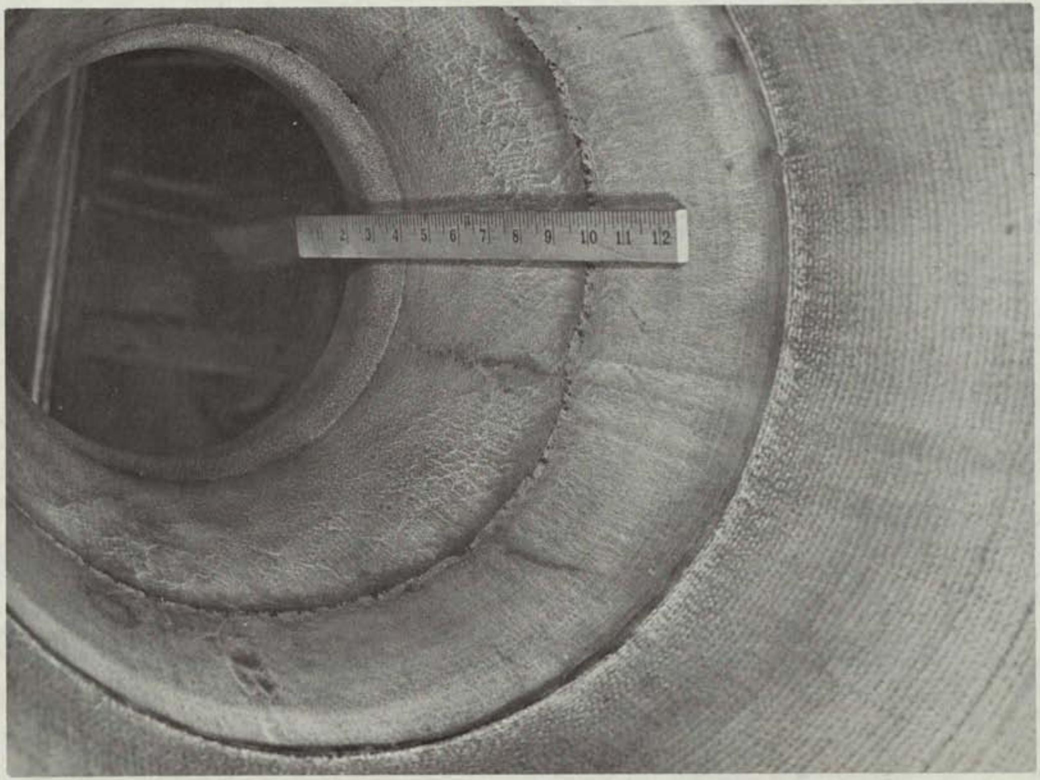


Figure 181. Nozzle No. 3 Exit Cone (View A)

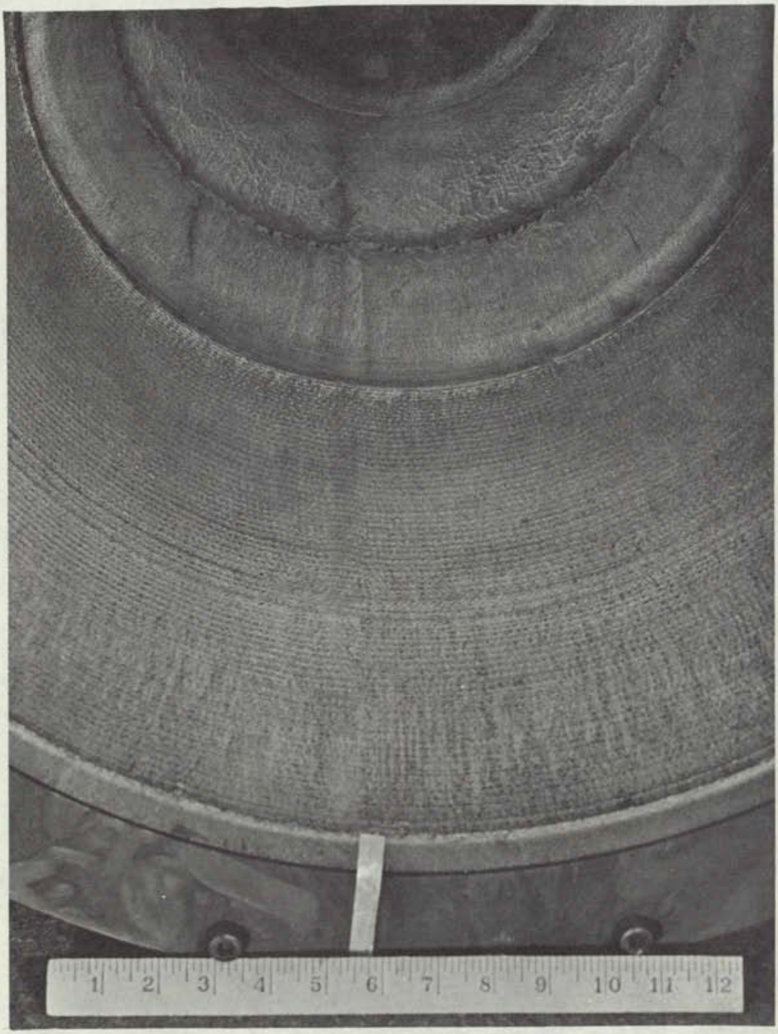


Figure 182. Nozzle No. 3 Exit Cone (View B)

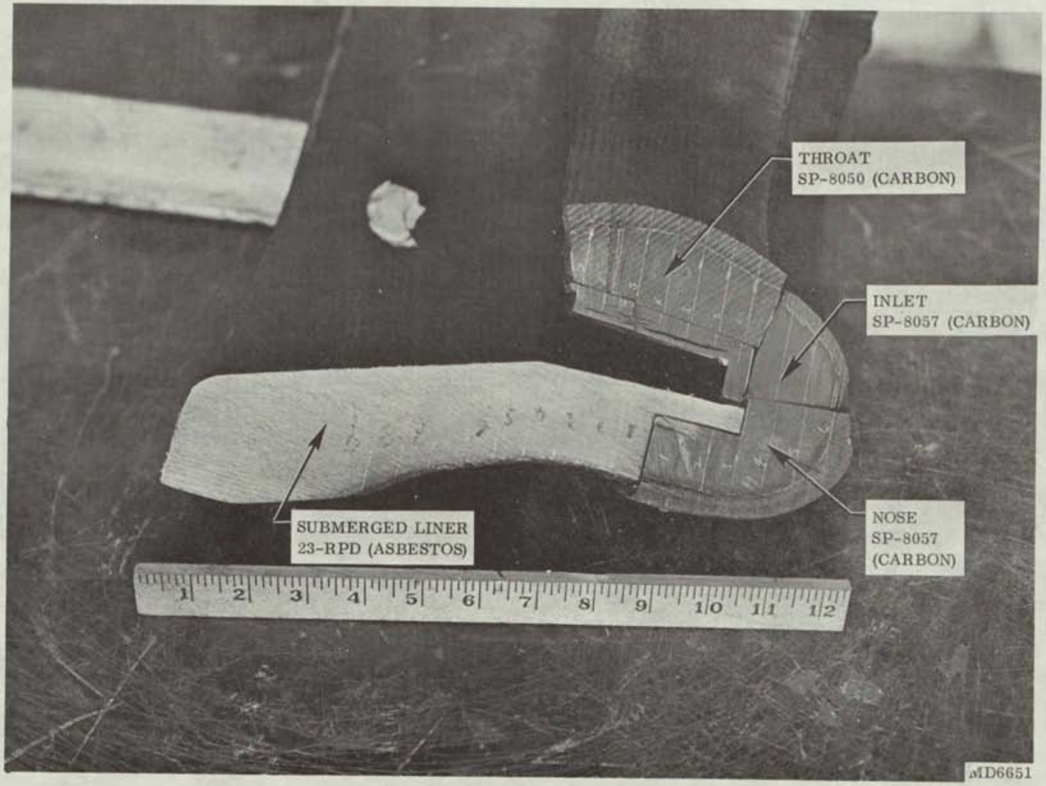


Figure 183. Sectioned Nozzle No. 3 Submerged Liners

Figure 184. Sectioned Nozzle No. 3 Exit Cone

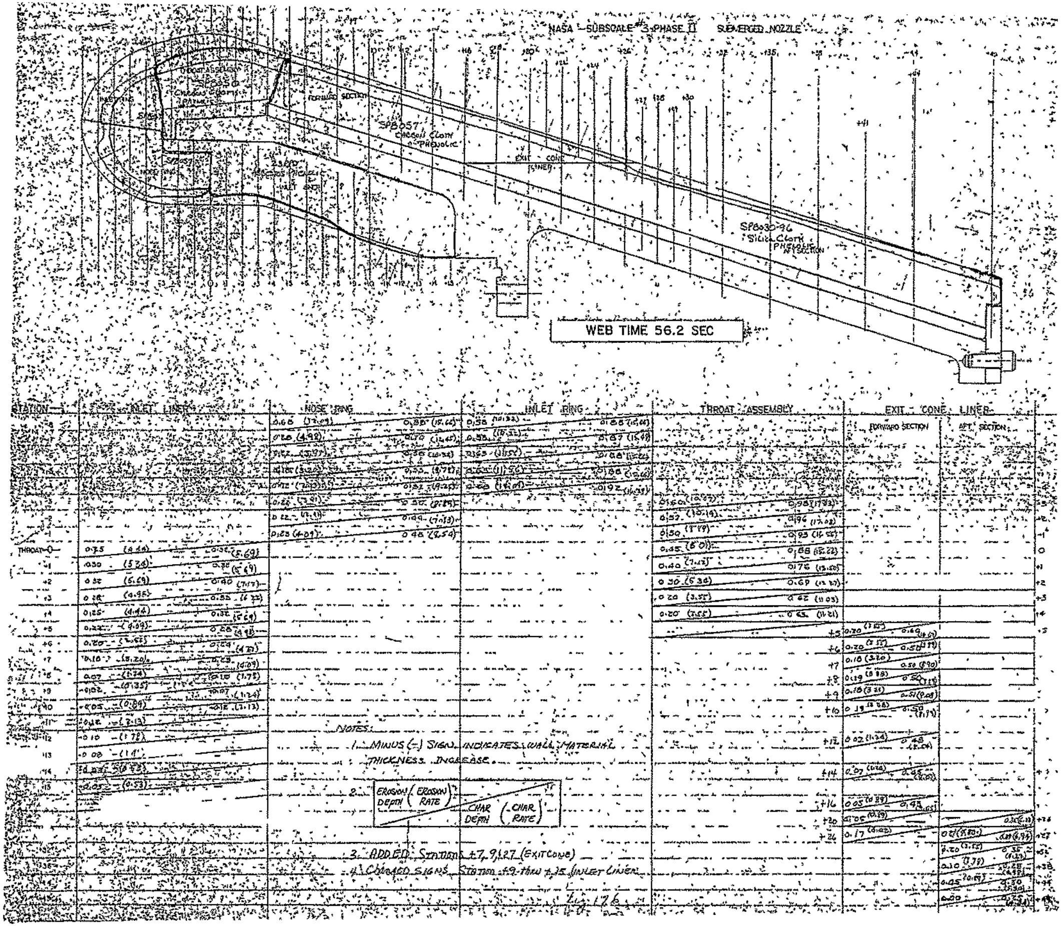


Figure 185. Nozzle No. 3 Erosion-Char Profile (Propellant Starpoint)

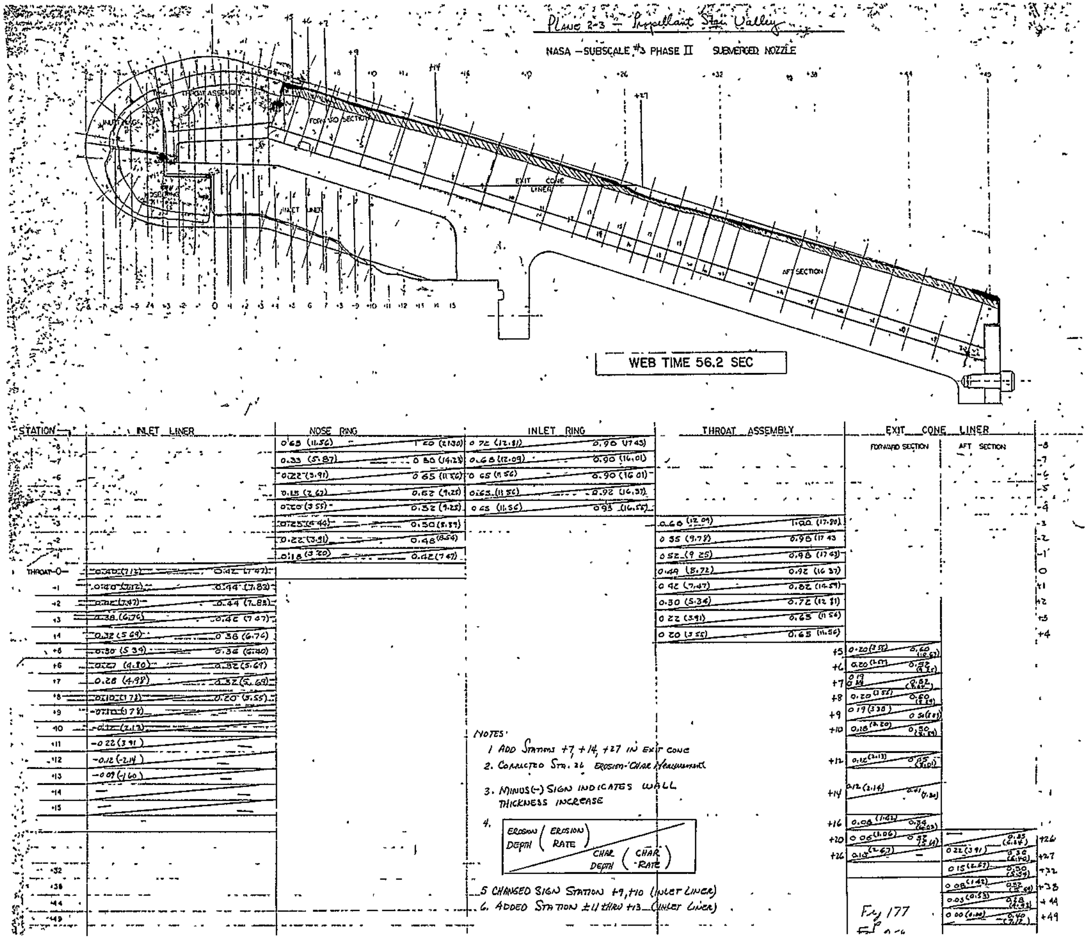


Figure 186. Nozzle No. 3 Erosion-Char Profile (Propellant Star Valley)

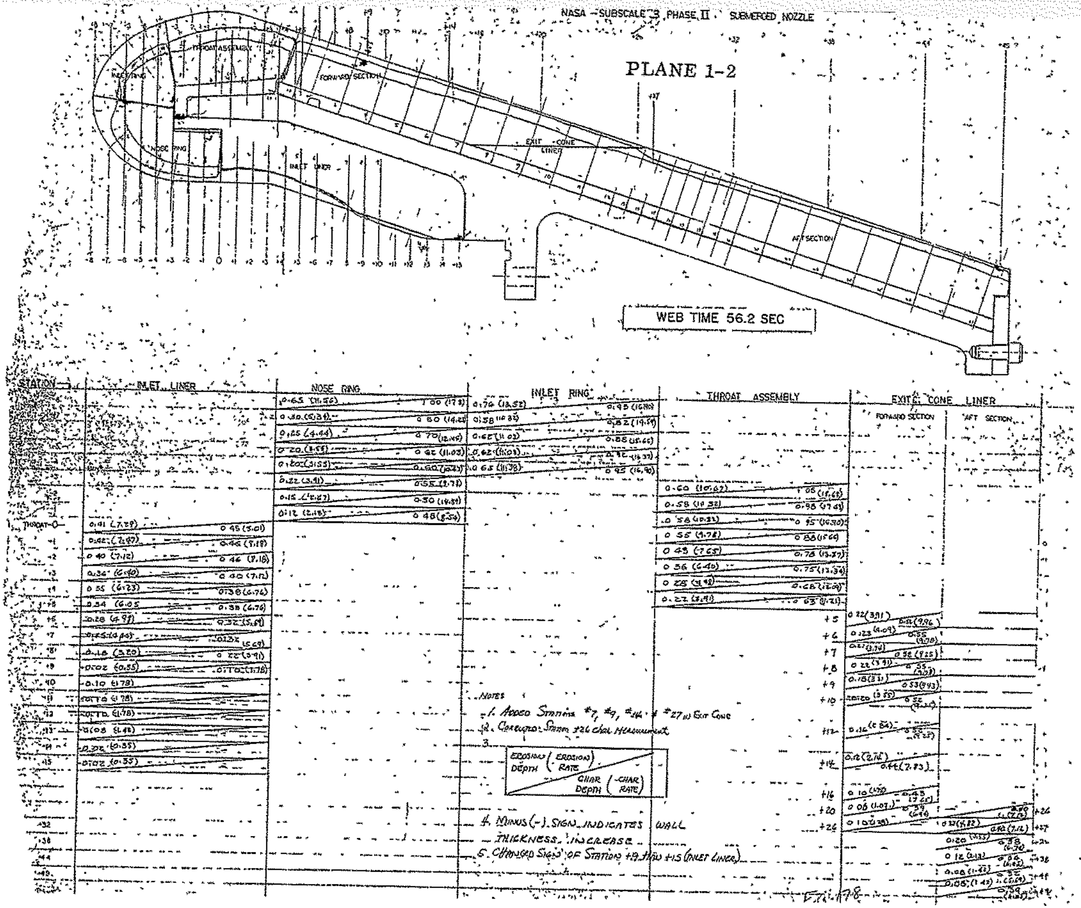


Figure 187. Nozzle No. 3 Erosion-Char Profile (Between Propellant Starpoint and Star Valley)

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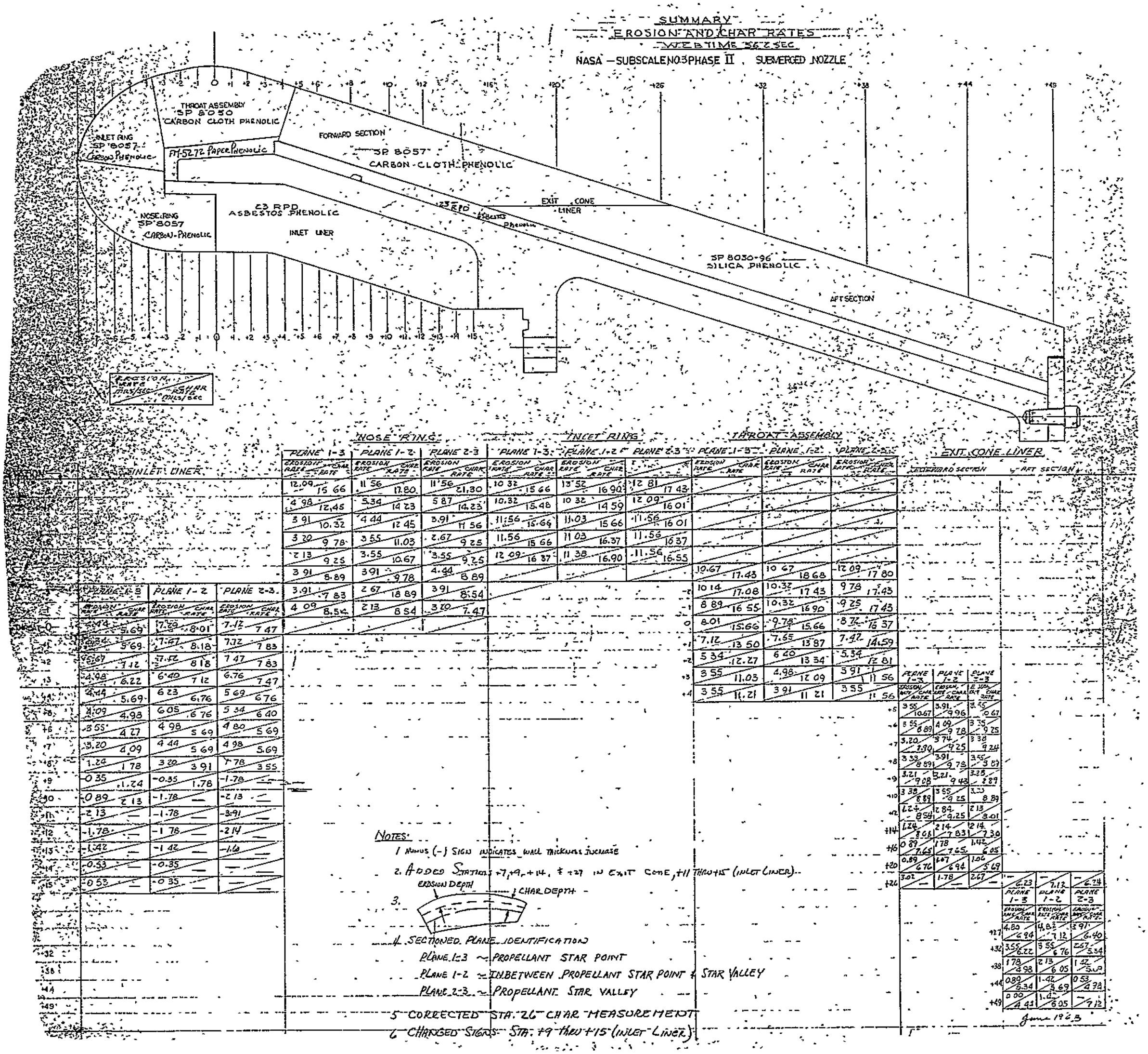


Figure 188. Nozzle No. 3 Three Plane Erosion-Char Rate Summary

TABLE 45

NOZZLE NO. 3 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged 23-RPD asbestos	Uniform erosion Axial surface wrinkles Very good performance
Nose SP-8057 carbon	Ply delaminations Uniform erosion Axial cracks Local spalling and gouging Good performance
Inlet SP-8057 carbon	Local gouging and delaminations Uniform erosion Very good performance
Throat SP-8050 carbon	Uniform erosion Ply delamination Excellent performance
Forward Exit SP-8057 carbon	Ply delaminations Low uniform erosion Very good performance
Aft Exit SP-8030-96 silica	Interface delamination Uniform erosion Very good performance

Insulation Liner	Comments
Exit Insulation 23-RPD asbestos	No delaminations Very satisfactory performance
Inlet-Throat Insulation FM-5272 paper	Localized delaminations Adequate performance

Figure 189. Nozzle No. 4 Submerged Liner

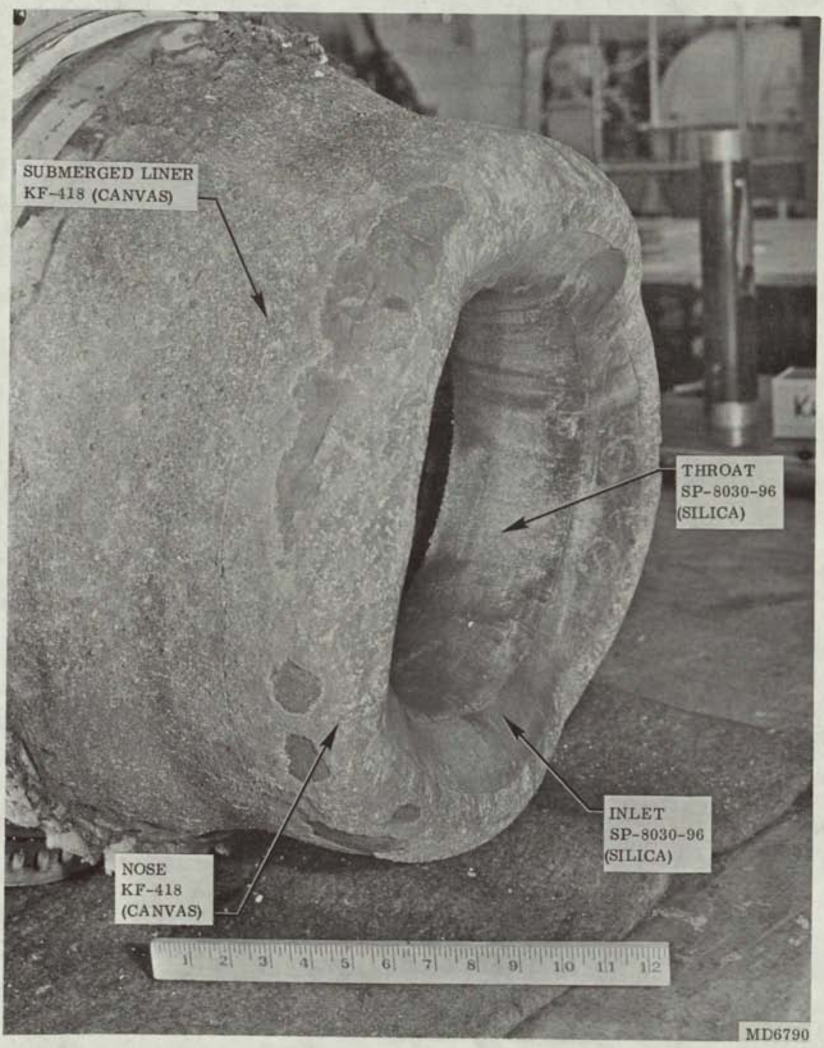


Figure 190. Nozzle No. 4 Submerged Liner, Nose, Inlet, and Throat

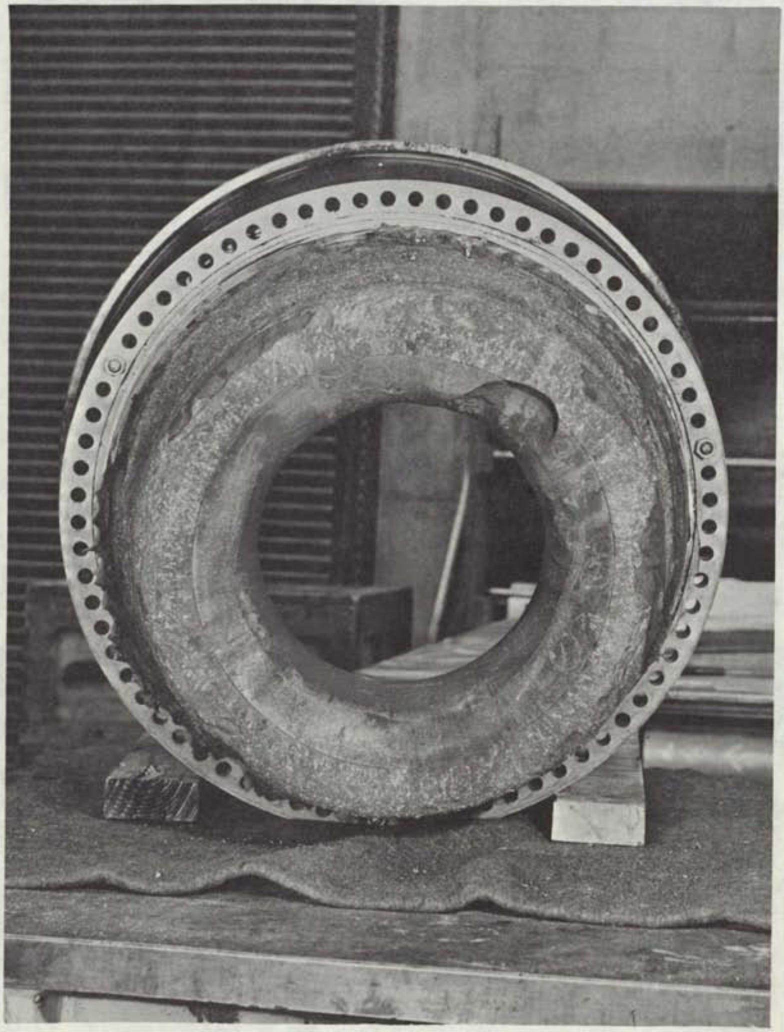


Figure 191. Nozzle No. 4 Nose and Inlet

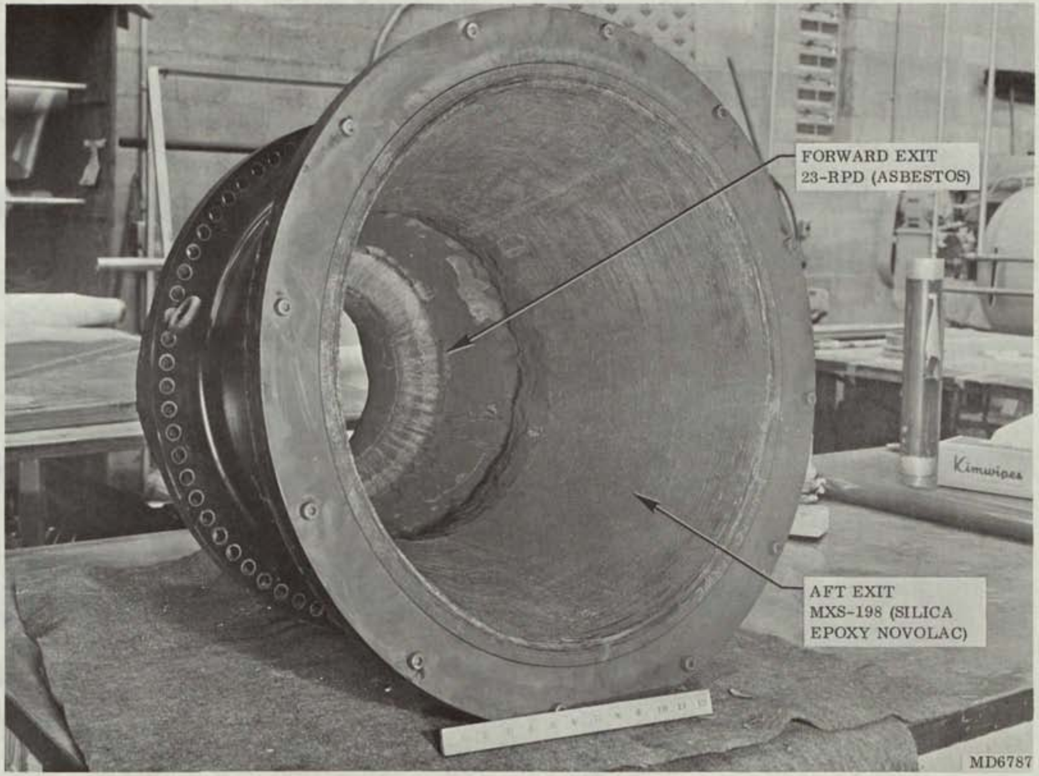


Figure 192. Nozzle No. 4 Exit Cone

Figure 193. Sectioned Nozzle No. 4 Submerged and Exit Cone Liners

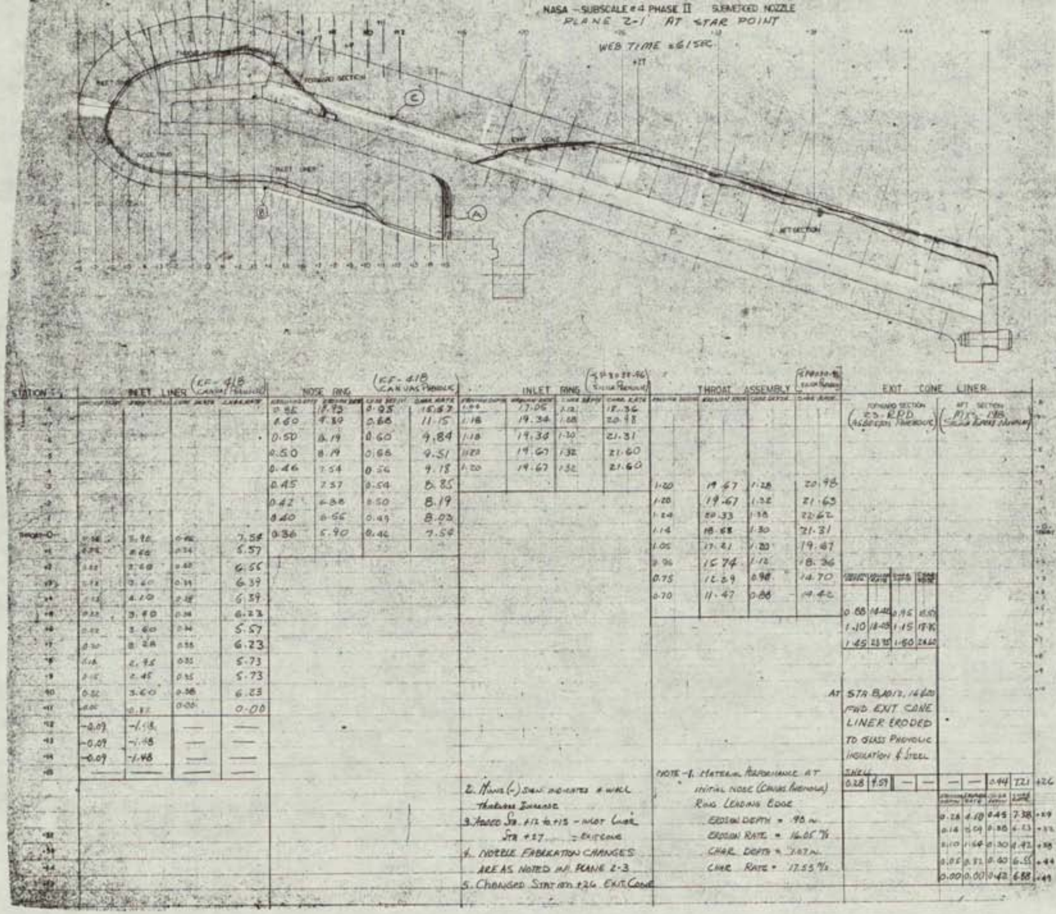
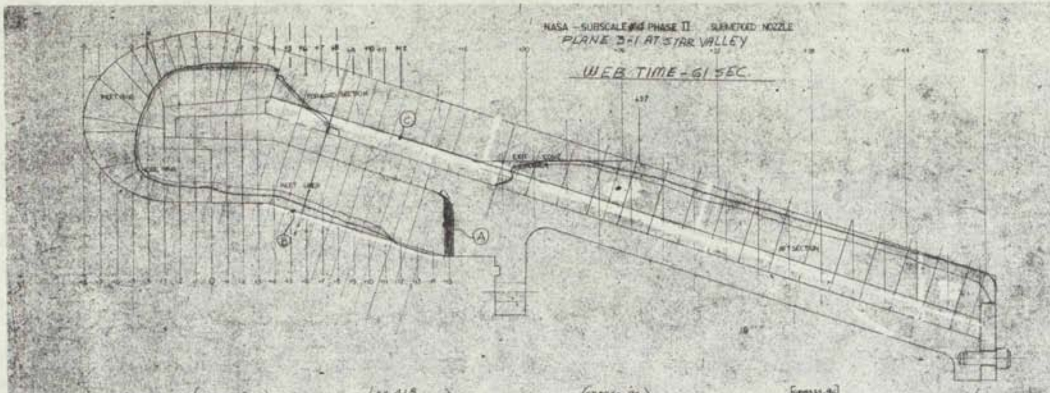


Figure 194. Nozzle No. 4 Erosion-Char Profile (Propellant Starpoint)



STATION	INLET LINER (KF-418 Carbon Phenolic)				NOSE RING (KF-418 Carbon Phenolic)				INLET RING (FM 5050-96 Silica Phenolic)				THROAT ASSEMBLY (FM 5030-96 Silica Phenolic)				EXIT CONE LINER Forward Section (ES RPD Asbestos Phenolic)				EXIT CONE LINER Aft Section (MXS-198 Silica Epoxy Novolac)				STATION
-8					1.65	27.05	1.75	28.68	1.75	28.68	1.88	30.49													-8
-7					1.16	18.85	1.25	20.49	1.75	28.68	1.82	29.84													-7
-6					0.83	13.61	0.92	15.08	1.65	25.41	1.65	27.05													-6
-5					0.68	11.15	0.78	12.78	1.38	22.62	1.48	24.26													-5
-4					0.60	9.84	0.70	11.47	1.20	19.67	1.28	20.98													-4
-3					0.53	8.68	0.68	11.15					1.08	17.70	1.12	18.36									-3
-2					0.50	8.19	0.60	9.84					1.05	17.21	1.12	18.36									-2
-1					0.45	7.37	0.63	10.33					1.05	17.21	1.15	18.85									-1
THROAT 0	0.68	7.32	0.63	10.33	0.45	7.37	0.63	10.33					1.00	16.39	1.10	18.03									0
+1	0.32	5.25	0.52	8.52									0.95	15.57	1.10	18.03									+1
+2	0.30	4.92	0.48	7.87									0.85	13.93	0.98	16.06									+2
+3	0.28	4.59	0.45	7.37									0.68	11.15	0.83	13.61									+3
+4	0.30	4.92	0.50	8.19									0.60	9.84	0.70	11.47									+4
+5	0.26	4.26	0.46	7.54													0.80	13.11	0.92	15.08					+5
+6	0.22	3.60	0.40	6.55													1.15	18.85	1.23	20.16					+6
+7	0.20	3.28	0.38	6.23													1.40	22.95	1.50	24.59					+7
+8	0.14	2.30	0.34	5.57																					+8
+9	0.14	2.30	0.34	5.57																					+9
+10	0.12	1.96	0.32	5.25																					+10
+11	0.05	0.82	0.15	2.46																					
+12	-0.06	-0.98	—	—																					
+13	-0.08	-1.31	—	—																					
+14	-0.07	-1.15	—	—																					
+15	—	—	—	—																					
+26																	0.36	5.90	—	—	[illegible]	[illegible]	0.52	7.52	+26
+27																					0.30	4.92	0.48	7.86	+27
+32																					0.25	4.10	0.50	8.19	+32
+38																					0.16	2.62	0.42	6.88	+38
+44																					0.06	1.97	0.30	4.92	+44
+47																					0.02	0.33	0.42	6.88	+47

AT STA. 8, 9, 10, 12, 14, 16 & 20 FWD. EXIT CONE LINER ERODED TO GLASS PHENOLIC INSULATION & STEEL SHELL

3. CHANGED STATION 126 EXIT CONE

3. ADDED STATION 127 EXTENDS INLET LINER

4. NOZZLE FABRICATION CHANGES Ⓐ Ⓑ Ⓒ ARE RELATED IN PHASE 2-3

NOTE - 1. MATERIAL PERFORMANCE AT INITIAL NOSE (CARBON PHENOLIC) RING LEADING EDGE
EROSION DEPTH = 1.78 in.
EROSION RATE = 29.2 mils
CHAR DEPTH = 1.87 in.
CHAR RATE = 30.6 mils

2. MINUS (-) INDICATES WALL THICKNESS INCREASE

SHEET II

Figure 195. Nozzle No. 4 Erosion-Char Profile (Propellant Star Valley)

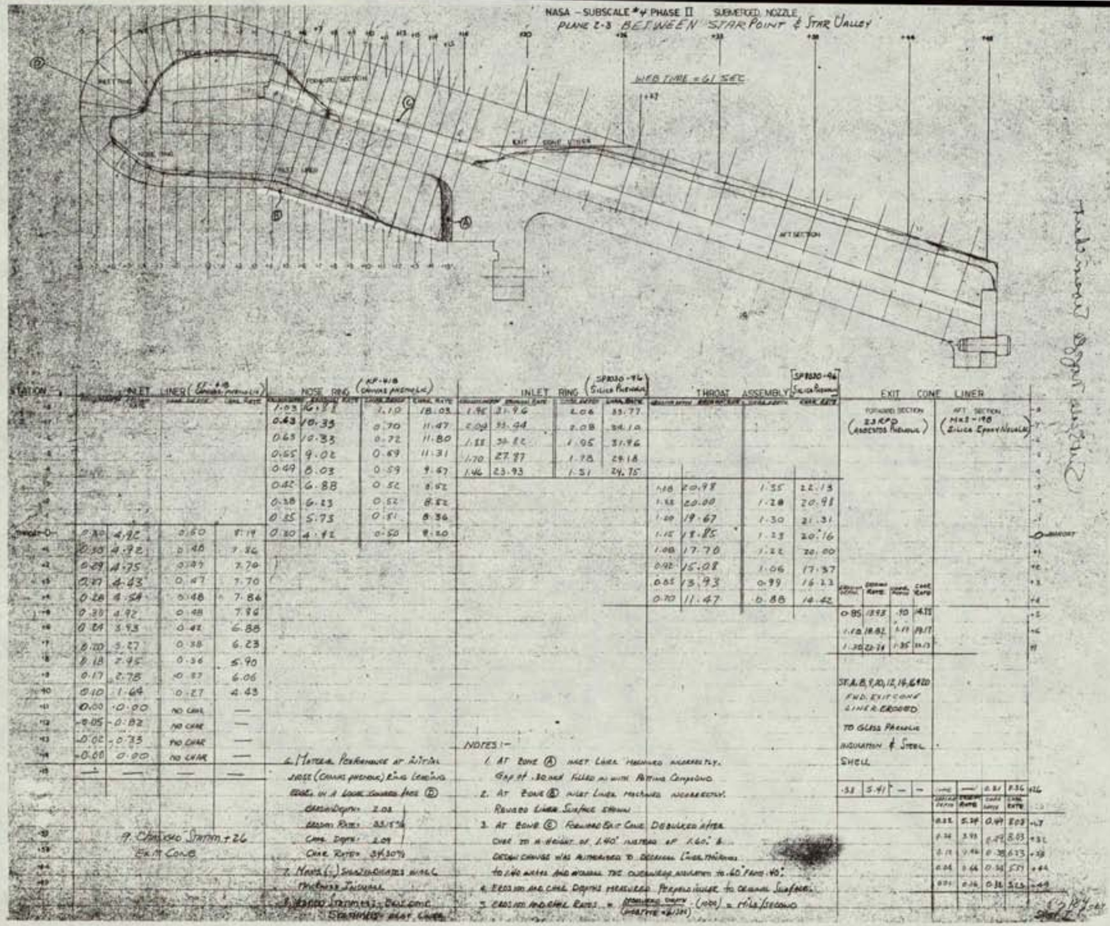


Figure 196. Nozzle No. 4 Erosion-Char Profile (Between Propellant Starpoint and Star Valley)

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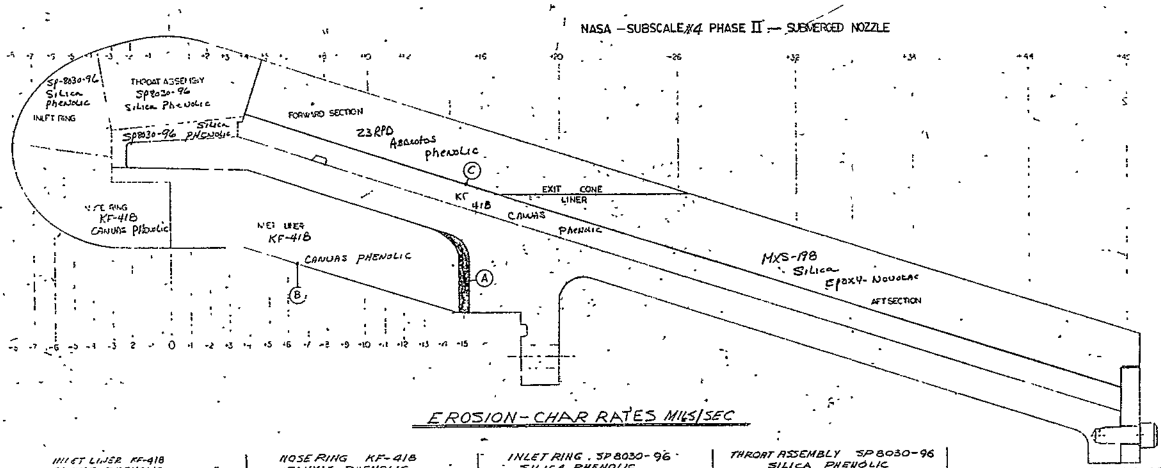


EROSION-CHAR RATES MILS/SEC

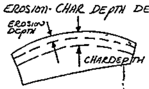
STATION		INLET LINER KF-418 CANVAS PHENOLIC PLANE Z-1	PLANE Z-3	PLANE 3-1	NOSE RING KF-418 CANVAS PHENOLIC PLANE Z-1	PLANE Z-3	PLANE 3-1	INLET RING SP8030-96 SILICA PHENOLIC PLANE Z-1	PLANE Z-3	PLANE 3-1
-8	EROS				3.93	16.88	27.05	17.05	31.96	28.68
	CHAR				15.57	18.03	28.68	18.36	33.77	30.49
-7	EROS				9.84	10.33	18.85	19.34	33.44	28.68
	CHAR				11.15	11.47	20.49	20.98	34.10	29.84
-6	EROS				8.19	10.33	13.61	19.34	30.82	25.41
	CHAR				9.84	11.60	15.06	21.31	31.96	27.05
-5	EROS				8.19	9.02	11.15	19.67	27.87	22.62
	CHAR				9.51	11.31	12.78	21.60	29.18	24.26
-4	EROS				7.54	8.03	9.84	19.67	23.93	19.67
	CHAR				9.18	9.67	11.47	21.60	24.75	20.98
-3	EROS				7.37	6.88	8.68			
	CHAR				8.85	8.52	11.15			
-2	EROS				6.88	6.23	8.19			
	CHAR				8.19	8.52	9.84			
-1	EROS				6.55	5.73	7.37			
	CHAR				8.03	8.36	10.33			
THROAT-0	EROS	5.90	4.92	7.37	5.90	4.92	7.37			
	CHAR	7.50	8.19	10.33	7.54	8.20	10.33			
+1	EROS	3.60	4.92	5.25						
	CHAR	5.5	7.86	8.52						
+2	EROS	3.60	4.75	4.92						
	CHAR	6.55	7.70	7.87						
+3	EROS	3.60	4.43	4.59						
	CHAR	6.39	7.70	7.37						
+4	EROS	4.10	4.59	4.92						
	CHAR	6.39	7.86	8.19						
+5	EROS	3.60	4.92	4.56						
	CHAR	6.23	7.86	7.54						
+6	EROS	3.60	3.93	3.60						
	CHAR	5.57	6.88	6.55						
+7	EROS	3.28	3.27	3.28						
	CHAR	6.23	6.23	6.23						
+8	EROS	2.95	2.95	2.30						
	CHAR	5.73	5.90	5.57						
+9	EROS	2.45	2.78	2.30						
	CHAR	5.73	6.06	5.57						
+10	EROS	3.60	1.64	1.96						
	CHAR	6.23	4.43	5.25						
+11	EROS	-0.82	2.00	0.82						
	CHAR	0.00	NONE	2.46						
+12	EROS	-1.48	-0.82	-0.98						
	CHAR	—	NONE	—						
+13	EROS	-1.48	-0.33	-1.31						
	CHAR	—	NONE	—						
+14	EROS	-1.48	0.00	-1.15						
	CHAR	—	NONE	—						
+15	EROS	—	—	0.00						
	CHAR	—	—	—						

STATION		THROAT ASSEMBLY SP8030-96 SILICA PHENOLIC PLANE Z-1	PLANE Z-3	PLANE 3-1	EXIT CONE LINER 23-RPD ASBESTOS PHENOLIC FORWARD SECTION PLANE Z-1	PLANE Z-3	PLANE 3-1	EXIT CONE LINER MXS-198 SILICA EPOXY NOVOLAC AFT SECTION PLANE Z-1	PLANE Z-3	PLANE 3-1
-3	EROS	19.67	20.98	17.70						
	CHAR	20.98	22.13	18.36						
-2	EROS	19.67	20.00	17.21						
	CHAR	21.63	20.98	18.36						
-1	EROS	20.35	19.67	17.21						
	CHAR	22.62	21.31	18.85						
-0-	EROS	18.68	18.85	16.39						
	CHAR	21.31	20.16	18.03						
+1	EROS	17.21	17.70	15.57						
	CHAR	19.67	20.00	18.03						
+2	EROS	15.74	15.08	13.93						
	CHAR	18.36	17.37	16.06						
+3	EROS	12.29	13.93	11.15						
	CHAR	14.70	16.23	13.61						
+4	EROS	11.47	11.47	9.84						
	CHAR	14.47	14.42	11.47						
+5	EROS				14.42	13.93	13.11			
	CHAR				15.57	14.75	15.08			
+6	EROS				18.03	18.02	18.52			
	CHAR				18.85	19.17	20.16			
+7	EROS				23.75	21.31	22.95			
	CHAR				24.60	22.13	24.59			
+26	EROS				4.59	5.41	5.90	—	—	—
	CHAR				—	—	—	7.21	8.36	8.52
+27	EROS							4.10	5.24	4.92
	CHAR							7.30	8.03	7.86
+32	EROS							2.29	3.93	4.10
	CHAR							6.23	8.03	8.19
+38	EROS							1.64	1.96	2.62
	CHAR							4.92	6.23	6.88
+44	EROS							0.82	0.66	0.52
	CHAR							6.55	5.57	4.92
+49	EROS							0.00	0.16	0.33
	CHAR							6.88	5.25	6.88

SEE NOTE ON PLANE SHEETS

NOTES:

1. ADDED STATIONS +12 to +15 AT INLET LINER
   " " +27 AT EXIT CONE
2. MINUS (-) SIGN INDICATES WALL THICKNESS INCREASE
3. SECTIONED PLANE INDENTIFICATION
   PLANE 2-1 ~ PROPELLANT STAR POINT
   PLANE 2-3 ~ INBETWEEN PROPELLANT STAR POINT & STAR VALLEY
   PLANE 3-1 ~ PROPELLANT STAR VALLEY
4. NOZZLE FABRICATION CHANGES (A) (B) (C) ARE AS NOTED IN SECTIONED PLANE 2-3
5. EROSION-CHAR DEPTH DEFINED



6. CHANGED STA. +26 EXIT CONE

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FOLDOUT FRAME

Figure 197. Nozzle No. 4 Three Plane Erosion-Char Rate Summary

FOLDOUT FRAME

TABLE 46

NOZZLE NO. 4 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged KF-418 canvas phenolic	Structural integrity Uniform erosion Weak char layer Very good performance
Nose KF-418 canvas phenolic	Local high erosion Localized gouge and spalling Weak char layer Structural integrity Fair to good performance
Inlet SP-8030-96 silica phenolic	Local high erosion Local gouge Structural integrity Fair to good performance
Throat SP-8030-96 silica phenolic	Local spalling and gouge High uniform erosion Structural integrity Good performance
Forward Exit 23-RPD asbestos phenolic	Liner lost High uniform erosion Poor performance
Aft Exit MXS-198 silica epoxy novolac	Interface spalling and gouge Ply delamination Uniform erosion Good performance

Insulation Liner	Comments
Exit Insulation KF-418 canvas phenolic	Local loss of insulation No delaminations Very satisfactory
Inlet-Throat Insulation SP-8030-96 silica phenolic	No delaminations Very satisfactory

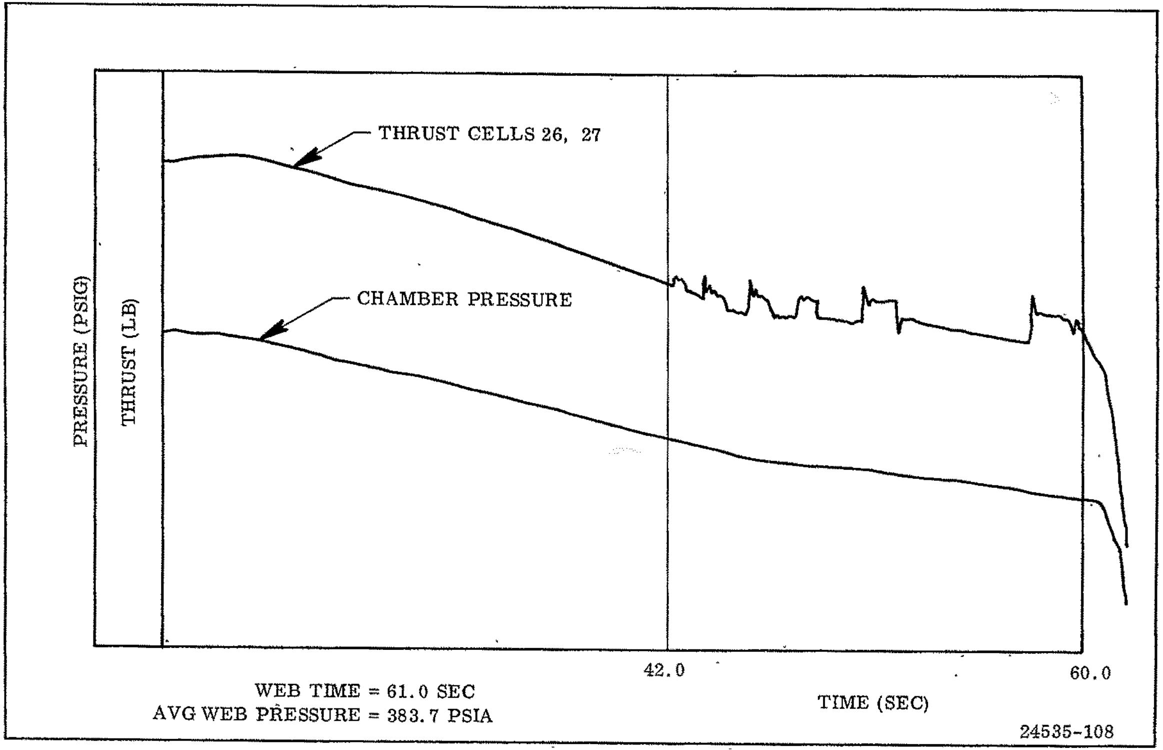


Figure 198. Partial Motor Pressure and Thrust, Nozzle No. 4

TABLE 47

NOZZLE NO. 4 FORWARD EXIT CONE TAG END TEST RESULTS
(23-RPD)

	Compression, Ult (psi)		Density (gm/cc)	
	Tag End	Control	Tag End	Control
	--	--	1.59	--
	12,425	--	1.60	--
	12,675	--	1.60	--
	13,250	13,650	1.63	--
	13,325	14,100	1.63	--
Avg	12,020	13,875	1.61	1.50

	Acetone Extraction	Residual Volatiles
Avg of 5 specimens (%)	2.30	3.33
Range of 5 specimens (%)	1.88 - 3.03	3.25 - 3.40

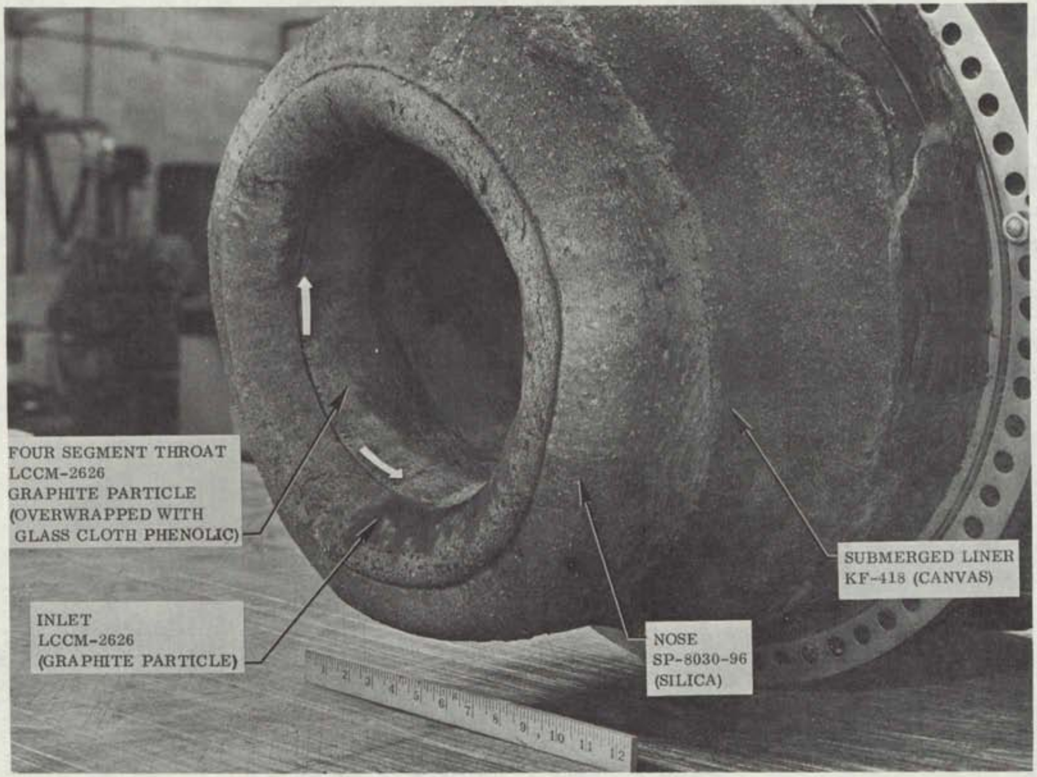


Figure 199. Nozzle No. 5 Submerged Liners

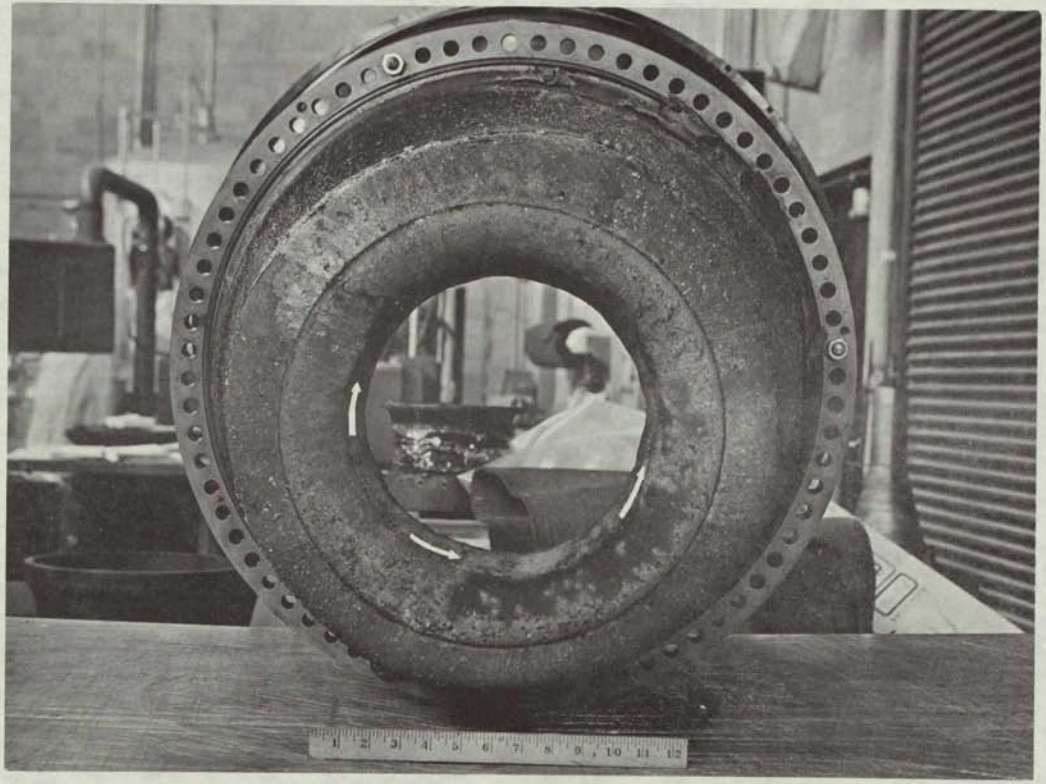


Figure 200. Nozzle No. 5 Nose, Inlet, and Throat

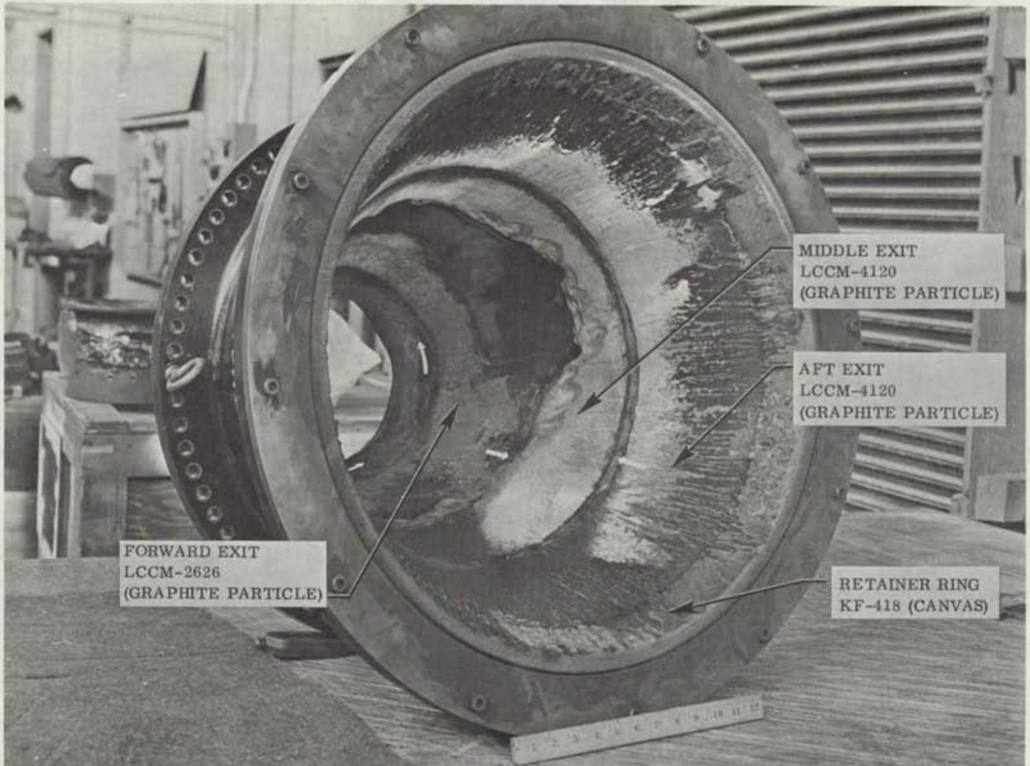


Figure 201. Nozzle No. 5 Exit Cone

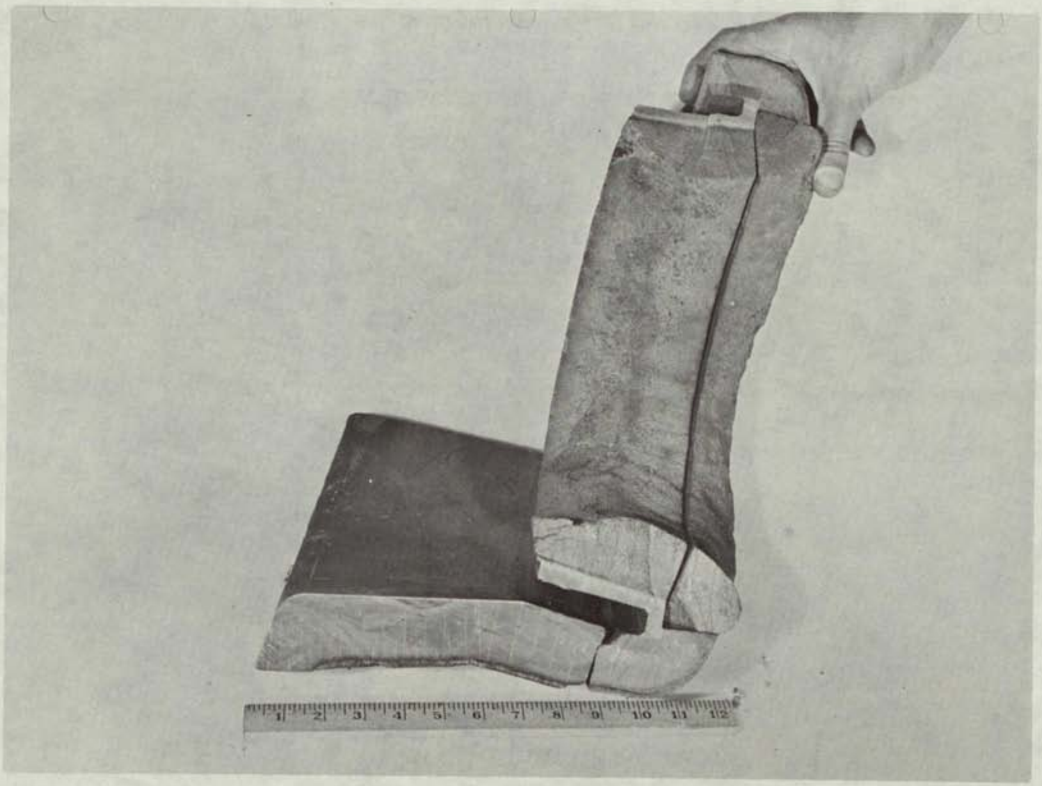


Figure 202. Sectioned Nozzle No. 5 Submerged Liners

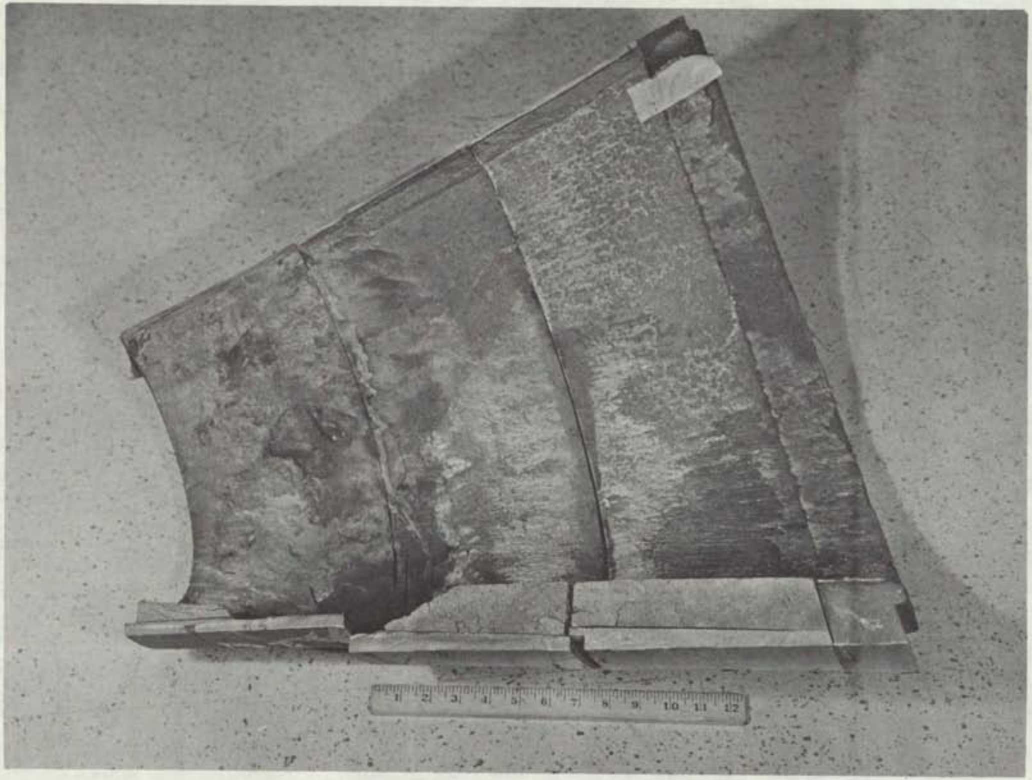


Figure 203. Sectioned Nozzle No. 5 Exit Cone Liners

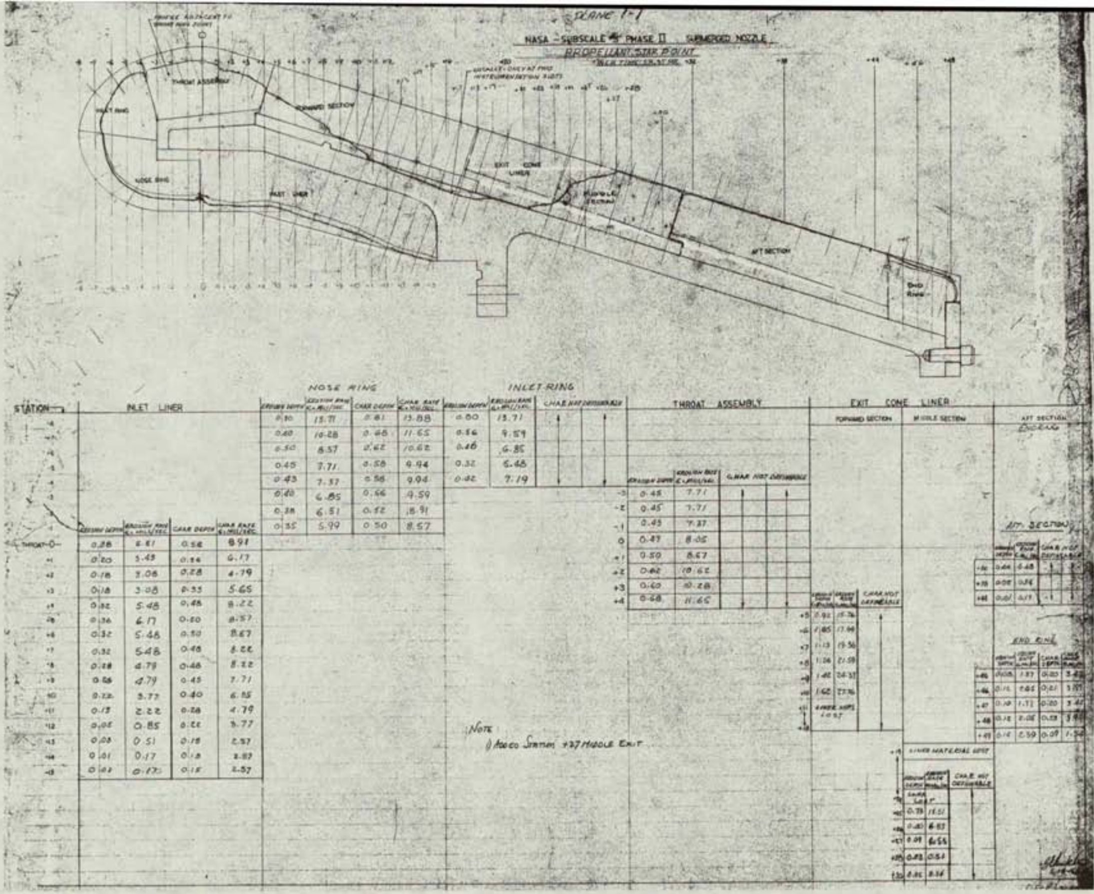
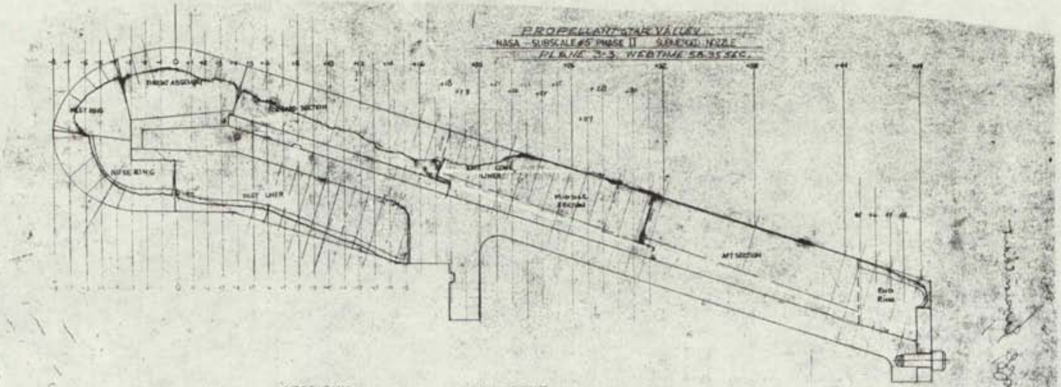


Figure 204. Nozzle No. 5 Erosion-Char Profile (Propellant Starpoint)



NOSE RING / INLET RING

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Depth	Char Rate (Mils/Sec)	Erosion Depth	Erosion Rate (Mils/Sec)	Char Not Definable
-8	1.15	19.71	1.30	22.28	1.00	17.14	↕
-7	1.08	18.51	1.18	20.22	0.51	8.74	↕
-6	0.86	14.74	0.95	16.28	0.55	9.42	↕
-5	0.73	12.51	0.82	14.05	0.55	9.42	↕
-4	0.65	11.14	0.78	13.36	0.56	9.60	↕
-3	0.60	10.28	0.75	12.85			
-2	0.53	9.08	0.73	12.51			
-1	0.58	9.94	0.72	12.34			

INLET LINER

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Depth	Char Rate (Mils/Sec)
THROAT-0-	0.60	10.28	0.75	12.86
+1	0.32	6.48	0.50	8.57
+2	0.25	4.28	0.42	7.19
+3	0.22	3.77	0.38	6.51
+4	0.23	3.94	0.40	6.85
+5	0.36	6.17	0.50	8.57
+6	0.40	6.85	0.55	9.42
+7	0.34	5.82	0.52	8.91
+8	0.32	5.48	0.48	8.22
+9	0.23	3.94	0.43	7.37
+10	0.22	3.77	0.38	6.51
+11	0.18	3.06	0.38	6.51
+12	0.12	2.05	0.28	4.79
+13	0.01	0.17	0.20	3.43
+14	-0.03	-0.51	0.18	3.08
+15	0.00	0.00	0.12	2.05

THROAT ASSEMBLY

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Not Definable
-3	0.66	11.31	↕
-2	0.68	11.65	↕
-1	0.70	11.99	↕
0	0.72	12.34	↕
+1	0.75	12.85	↕
+2	0.85	14.56	↕
+3	0.73	12.51	↕
+4	0.68	11.65	↕

EXIT CONE LINER

FORWARD SECTION

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Not Definable
+5	0.176	13.00	
+6	0.90	15.42	↕
+7	0.86	14.74	↕
+8	0.95	16.28	↕
+9	1.00	17.14	↕
+10	1.05	17.65	↕
+11	1.09	18.70	↕
+12	1.02	17.48	↕
+14	1.38	21.83	↕
+16	1.22	20.91	↕
+18	1.08	18.51	↕

MIDDLE SECTION

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Not Definable
+19	0.96	16.45	↕
+20	0.90	15.42	↕
+21	0.65	11.14	↕
+22	0.21	4.13	↕
+23	[illegible]	[illegible]	↕
+24	0.00	0.00	↕

AFT SECTION

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Not Definable
[illegible]	0.03	3.61	↕
[illegible]	0.02	3.54	↕
[illegible]	0.00	1.08	↕

END RING

STATION	Erosion Depth	Erosion Rate (Mils/Sec)	Char Depth	Char Rate (Mils/Sec)
+45	0.01	0.34	0.25	4.18
+46	0.03	0.51	0.25	4.25
+47	0.05	0.85	0.25	4.28
+48	0.10	1.71	0.30	5.14
+49	0.15	2.23	0.33	5.65

NOTES:

1. MINUS (-) SIGN INDICATES WALL THICKNESS DECREASE

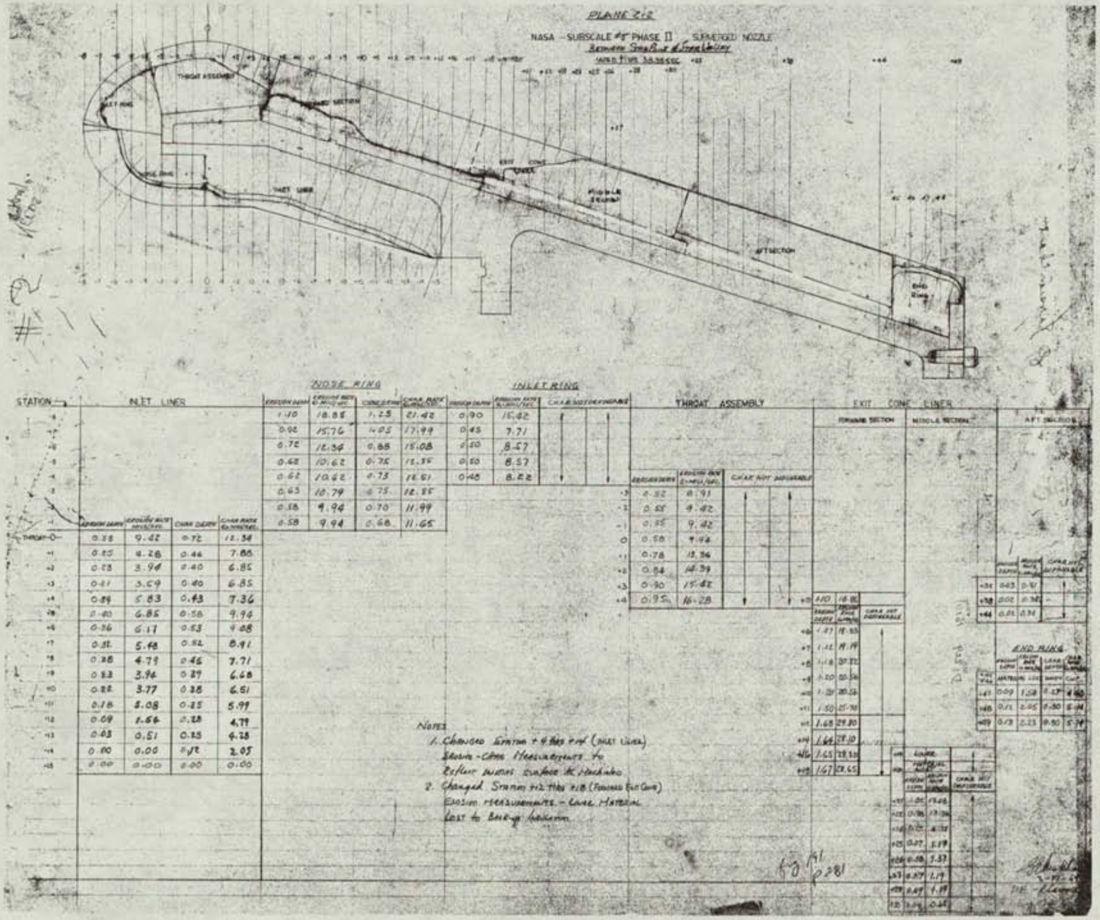
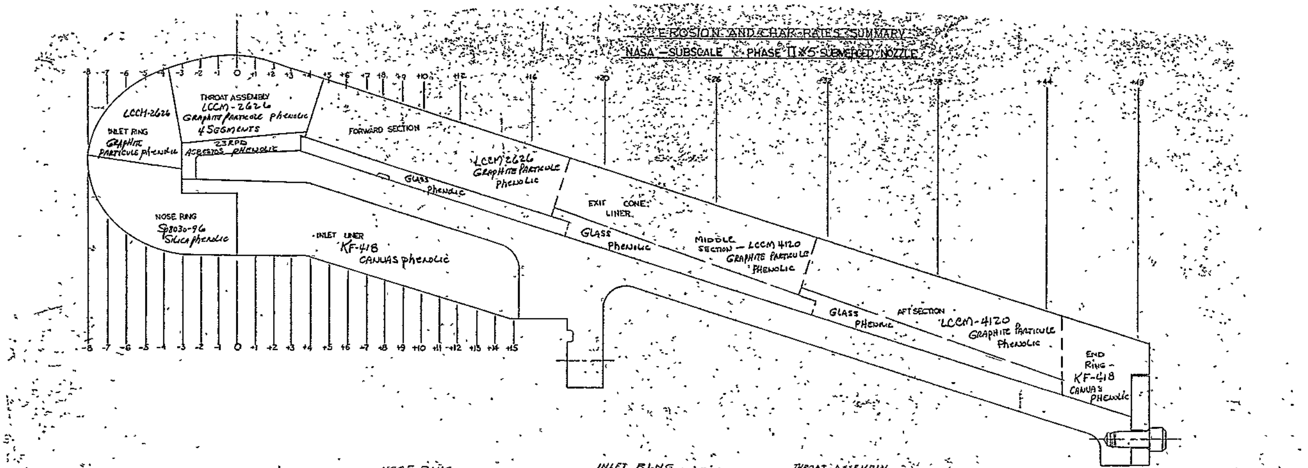


Figure 206. Nozzle No. 5 Erosion-Char Profile (Between Propellant Starpoint and Star Valley)



INLET LINER – CANVAS PHENOLIC KF-418 (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
THROAT 0	6.51 / 8.91	9.42 / 12.34	10.28 / 12.85
+1	3.43 / 6.17	4.28 / 7.88	5.48 / 8.57
+2	3.08 / 4.79	3.94 / 6.85	4.28 / 7.19
+3	3.08 / 5.65	3.59 / 6.85	3.77 / 6.51
+4	5.48 / 8.22	5.83 / 7.36	3.94 / 6.85
+5	6.17 / 8.57	6.85 / 9.94	6.17 / 8.57
+6	5.48 / 8.57	6.17 / 9.08	6.85 / 9.42
+7	5.48 / 8.22	5.48 / 8.91	5.82 / 8.91
+8	4.79 / 8.22	4.79 / 7.71	5.48 / 8.22
+9	4.79 / 7.71	3.94 / 6.68	3.94 / 7.37
+10	3.77 / 6.85	3.77 / 6.55	3.77 / 6.51
+11	2.22 / 4.79	3.08 / 5.99	3.05 / 6.51
+12	0.85 / 3.77	7.54 / 4.79	2.05 / 4.79
+13	0.51 / 2.57	0.61 / 4.28	0.17 / 3.43
+14	0.17 / 2.57	0.00 / 2.05	-0.51 / 3.08
+15	0.17 / 2.57	0.00 / 0.00	0.00 / 2.05

NOSE RING – SILICA PHENOLIC SP80-30-96 (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
-8	13.71 / 13.88	18.85 / 21.42	19.71 / 22.28
-7	10.28 / 11.65	15.76 / 17.99	18.51 / 20.22
-6	8.57 / 10.62	12.34 / 15.08	14.74 / 16.28
-5	7.71 / 9.94	10.62 / 12.85	12.51 / 14.05
-4	7.37 / 9.94	10.62 / 12.51	11.14 / 13.36
-3	6.85 / 9.59	10.79 / 12.85	10.28 / 12.85
-2	6.51 / 8.91	9.94 / 11.99	9.08 / 12.51
-1	5.99 / 8.57	9.94 / 11.65	9.94 / 12.34

INLET RING – GRAPHITE PARTICLE-PHENOLIC T-2626 (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
-8	13.71 / ②	15.42 / ②	17.74 / ②
-7	9.59	7.71	8.74
-6	6.85	8.57	9.42
-5	5.48	8.57	9.42
-4	7.19	8.22	9.60

THROAT ASSEMBLY – GRAPHITE PARTICLE PHENOLIC T-2626 (SEGMENTED) (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
-3	7.71 / ②	8.91 / ②	11.31 / ②
-2	7.71	9.42	11.65
-1	7.37	9.42	11.99
0	8.05	9.94	12.34
+1	8.57	13.36	12.85
+2	10.62	14.39	14.56
+3	10.28	15.42	12.51
+4	11.65	16.28	11.65

GRAPHITE PARTICLE T-2626 – FORWARD SECTION (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
+5	15.75 / ②	18.85 / ②	13.02 / ②
+6	17.99	18.33	15.42
+7	19.34	19.19	14.56
+8	21.59	20.22	15.28
+9	27.33	20.56	17.19
+10	27.76	20.56	17.65
+11		29.70	18.72
+12		29.80	17.30
+14	LINER	28.10	21.93
+16	MTL	28.30	20.91
+18	LOST	22.65	18.51

GRAPHITE PARTICLE PHENOLIC T-4120 – MIDDLE SECTION (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
+19	LINER MAT'L LOST	MAT'L	16.65
+20		LOST	15.43
+21		17.49	11.14
+22		18.36	4.37
+24		4.28	0.00
+25	12.51	1.19	0.03
+26	6.85	1.37	0.03
+27	1.65	1.19	0.09
+28	0.51	1.19	0.00
+30	0.34	0.69	0.00

GRAPHITE PARTICLE PHENOLIC T-4120 – AFT SECTION

END RING

AFT SECTION LCCM T-4120 (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
+32	0.68	0.51	0.51
+35	0.34	0.34	0.34
+41	0.17	0.34	0.69

CANVAS PHENOLIC KF-418 END RING (erosion / char)

STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
+45	1.37 / 3.42	MAT'L	0.34 / 4.28
+46	2.25 / 3.59	LOST	1.51 / 4.28
+47	1.71 / 3.42	1.54 / 4.37	0.35 / 4.23
+48	2.39 / 3.99	2.05 / 5.14	1.71 / 5.14
+49	2.33 / 1.54	2.23 / 5.14	2.73 / 5.48

EROSION AND CHAR RATES MILS/SEC

NOTES: 1. EROSION / CHAR

PLANE 1-1 AT PROPELLANT STAR POINT

PLANE 2-2 AT BETWEEN STAR POINT AND STAR VALLEY

PLANE 3-3 AT PROPELLANT STAR VALLEY

2. BLANK CHAR RATE SPACES INDICATE CHAR NOT DEFINEABLE

3. Added Stations +12, +14, +16, +18 in Forward Exit Cone.

4. Changed Station +4 thru +14 for Plane 2-2 (Inlet Liner) to Reflect initial surface as Machined.

5. Changed Station +12 thru +18 for Plane 2-2 (Exit Cone) Liner Material Lost to Back-up Insulation

6. MINUS (-) SIGN INDICATES WALL THICKNESS INCREASE

7.

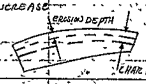


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Figure 207. Nozzle No. 5 Three Plane Erosion-Char Rate Summary

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TABLE 48

NOZZLE NO. 5 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged Liner KF-418 canvas phenolic	Uniform erosion Weak char layer Structural integrity Good performance
Nose SP-8030-96 silica phenolic	Local high erosion Ply delaminations Structural integrity Good performance
Inlet LCCM-2626 graphite particle phenolic	Low uniform erosion Delaminations and cracks Local spalling Good performance
Throat LCCM-2626 graphite particle phenolic	Uniform erosion Internal delaminations Local spalling Fair to good performance
Forward Exit Cone LCCM-2626X graphite particle phenolic	High nonuniform erosion Spalling and gouging Internal delaminations Liner lost locally Poor to fair performance
Middle Exit Cone LCCM-4120 graphite particle phenolic	Interface gouging and spalling Low uniform erosion Delaminations and cracks Fair to good performance
Aft Exit Cone LCCM-4120 graphite particle phenolic	Low uniform erosion Delaminations and cracks Good performance

Insulation Liner	Comments
Exit Cone Insulation 1581 glass phenolic	No delaminations Prevented loss of steel shell Very satisfactory
Inlet-Throat Insulation 23-RPD asbestos phenolic	Local delaminations Satisfactory

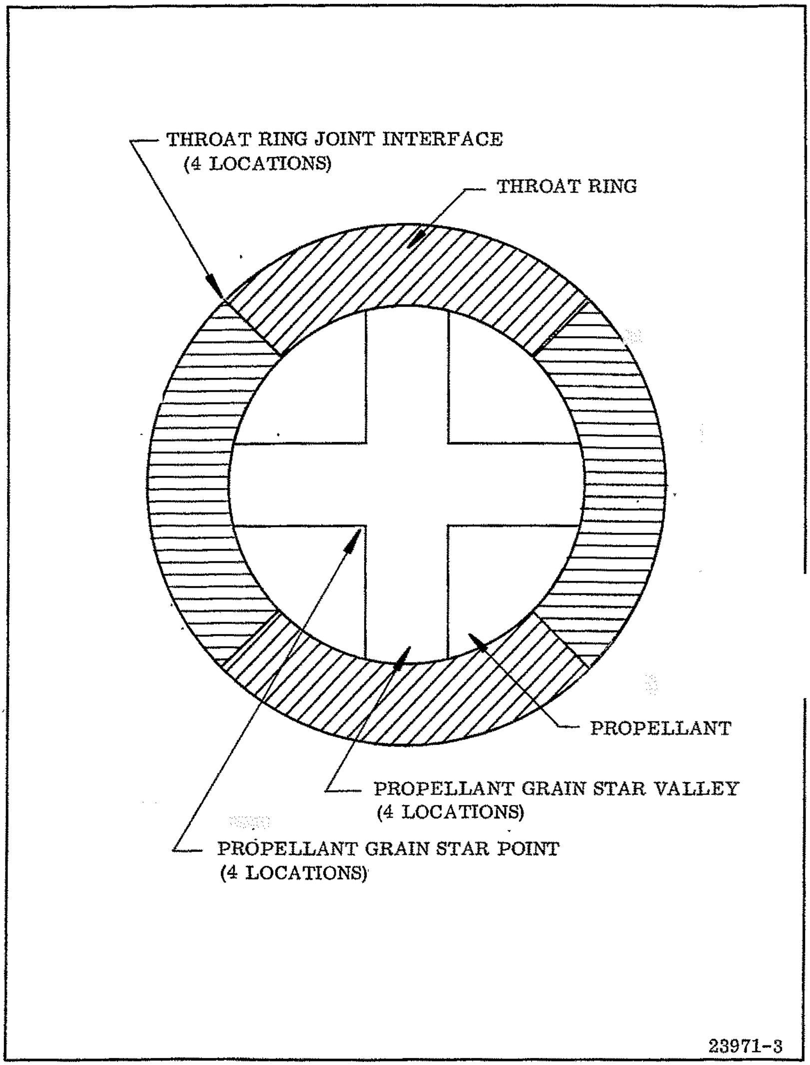


Figure 208. Throat Ring Segment Orientation to Propellant Grain

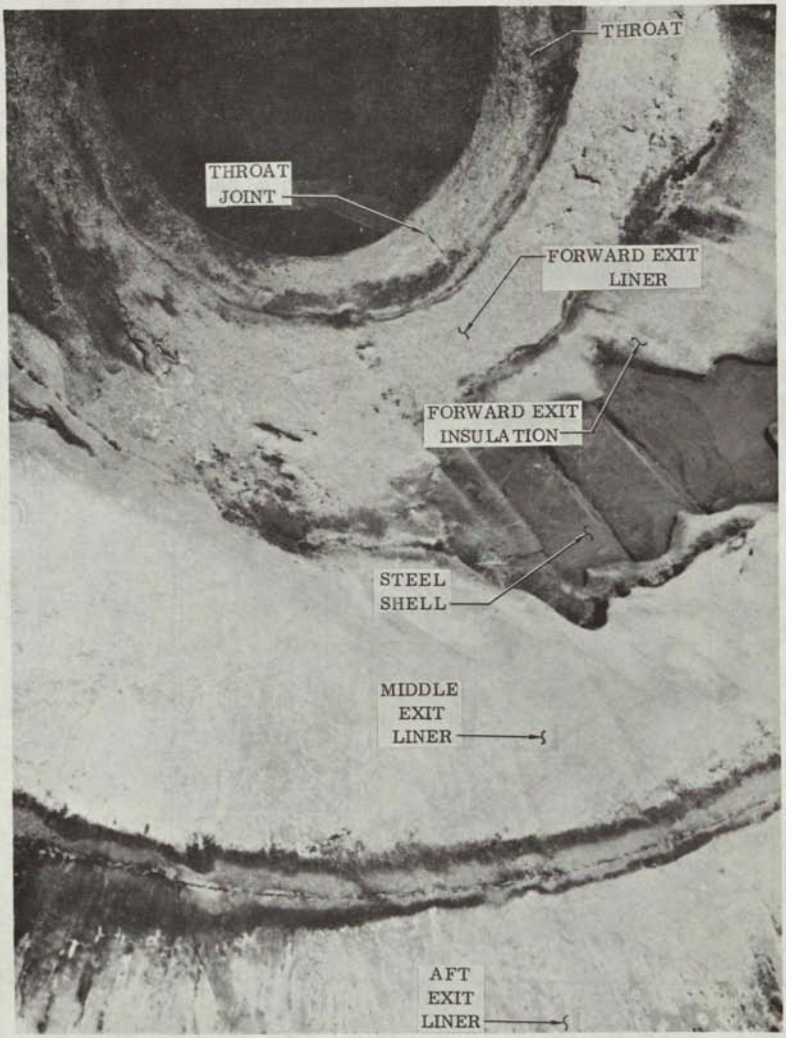


Figure 209. Nozzle No. 5 Exit Cone with Steel Shell Exposed

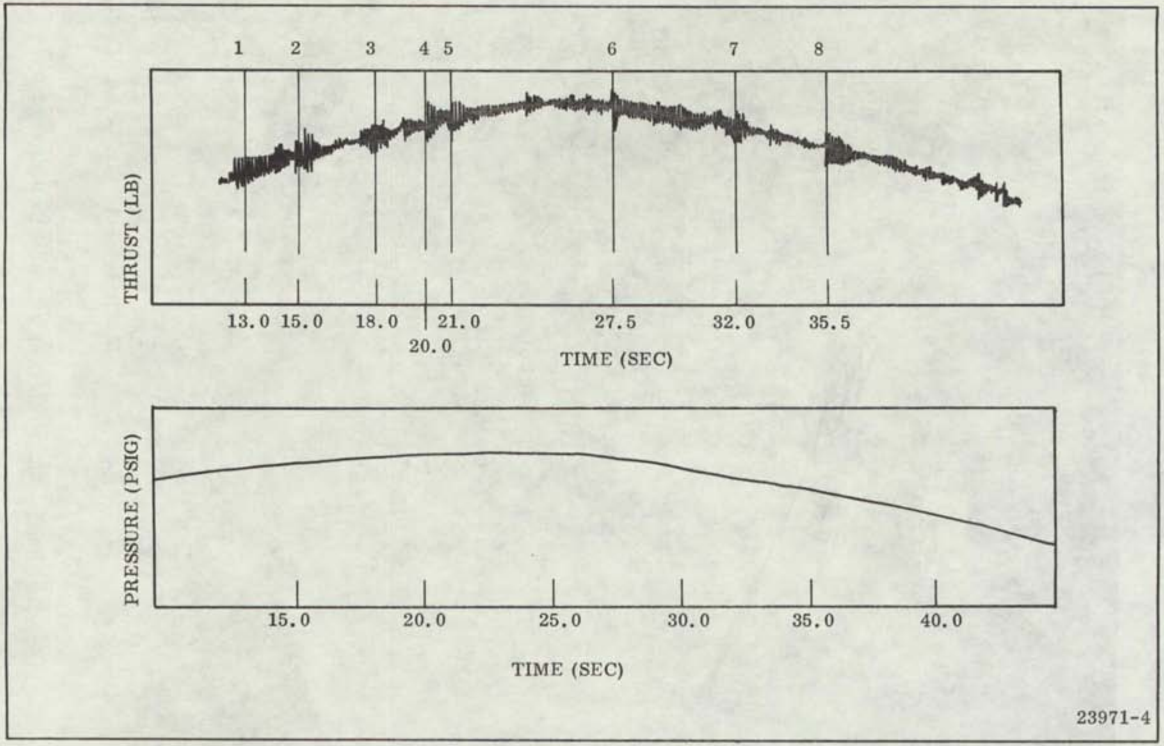


Figure 210. Nozzle No. 5 Motor Performance

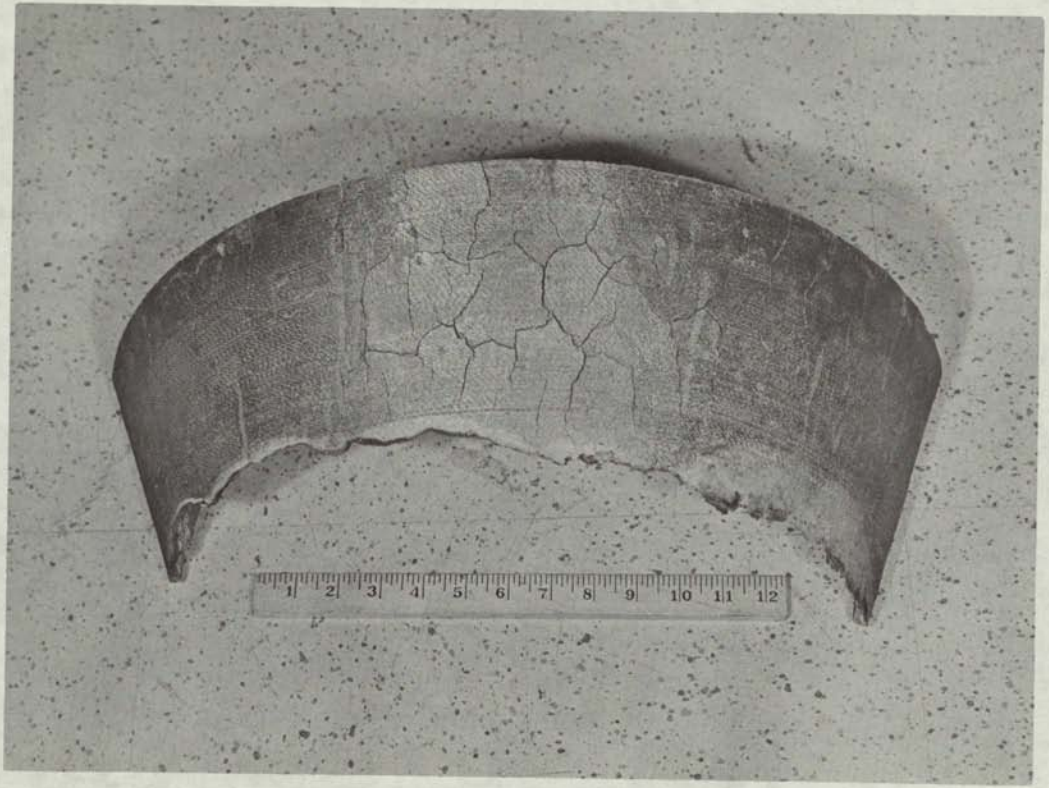


Figure 211. Middle Exit Cone Liner OD Surface

Figure 212. Nozzle No. 6 Submerged Liner and Nose

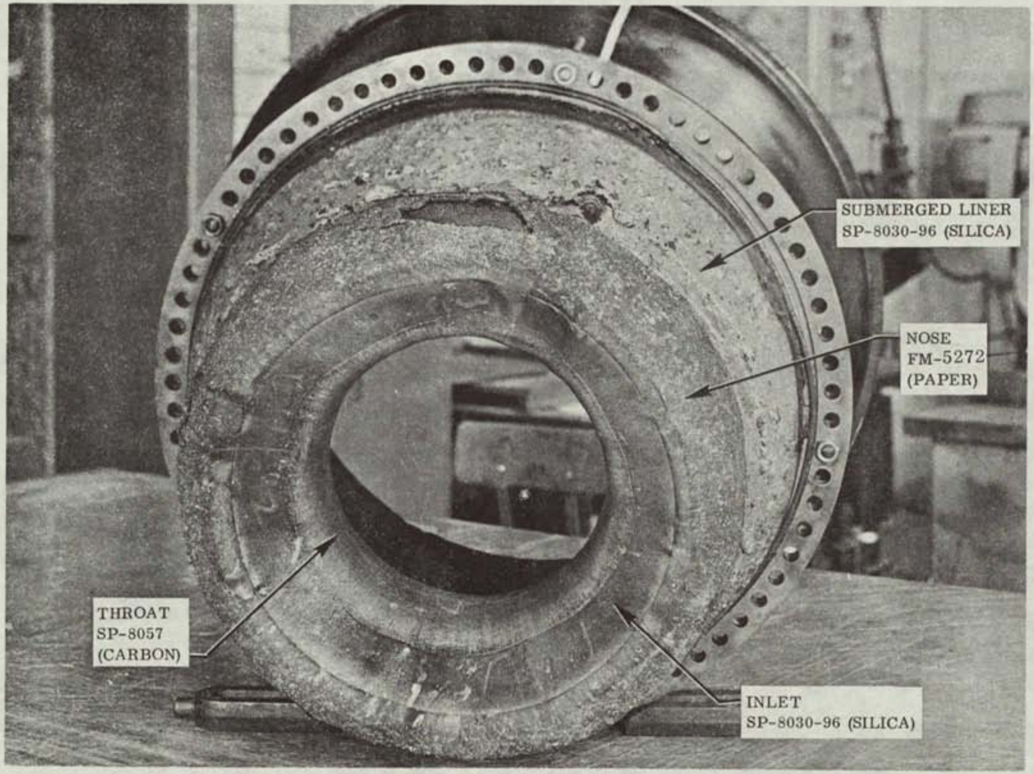


Figure 213. Nozzle No. 6 Submerged Liners

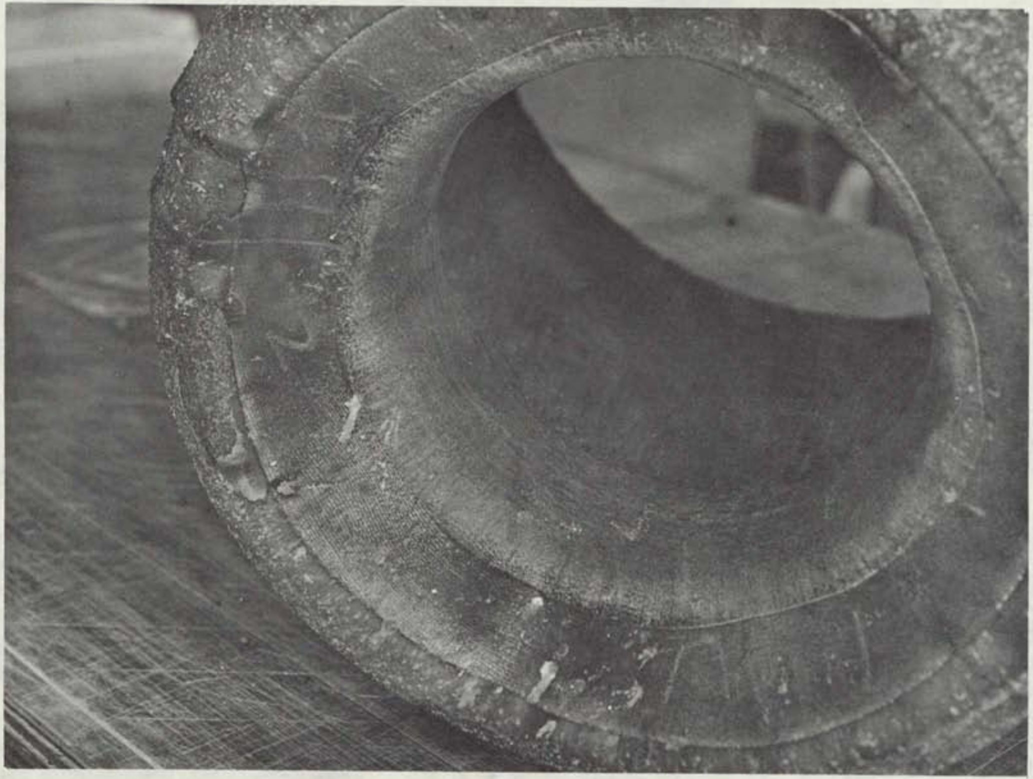


Figure 215. Nozzle No. 6 Exit Cone

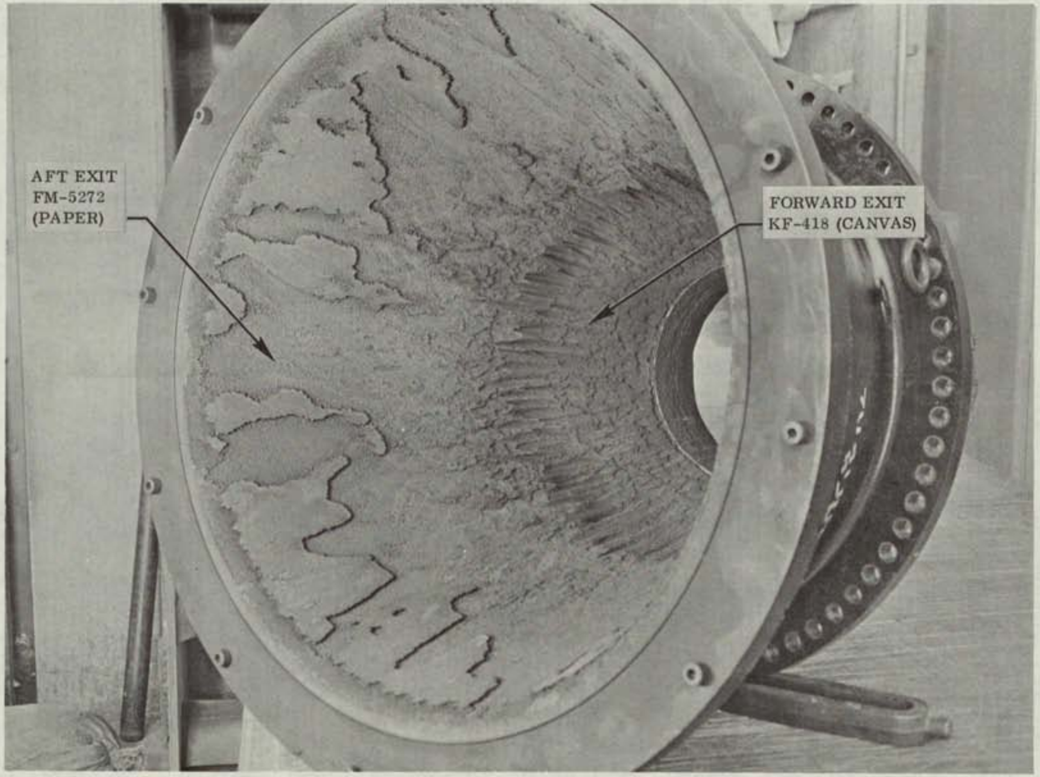


Figure 216. Sectioned Nozzle No. 6 Submerged and Exit Cone Liners

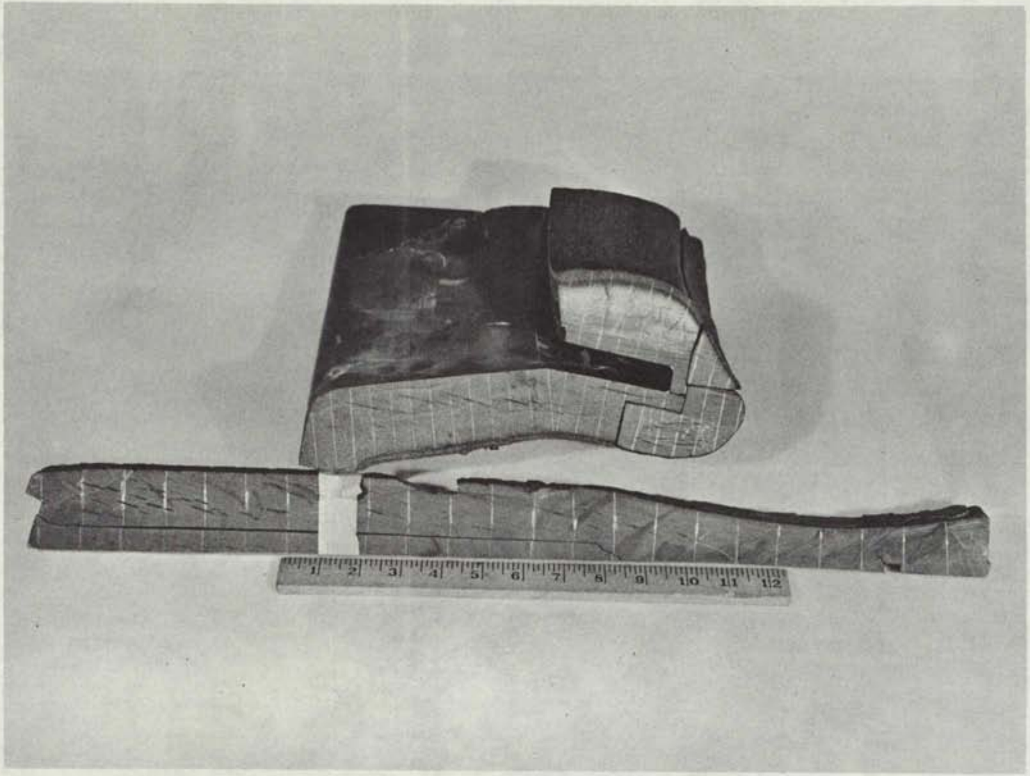
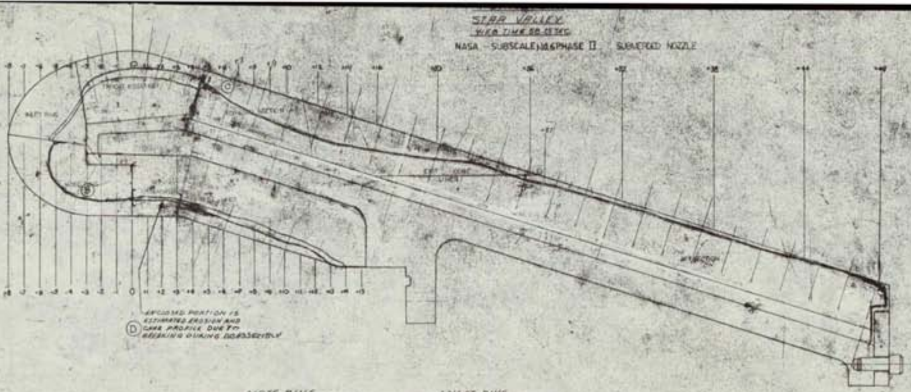


Figure 216. Sectioned Nozzle No. 6 Submerged and Exit Cone Liners



NOSE RING / INLET RING

STATION	Nose Ring Erosion Depth	Nose Ring Erosion Rate mils/sec	Nose Ring Char Depth	Nose Ring Char Rate mils/sec	Inlet Ring Erosion Depth	Inlet Ring Erosion Rate mils/sec	Inlet Ring Char Depth	Inlet Ring Char Rate mils/sec
-8	CHAR LOST IN OVEN HEATER DURING DISASSEMBLY	SEE NOTE	1.55	26.40	1.34	22.80	1.48	25.41
-7			1.00	17.16	1.50	25.75	1.62	27.81
-6			0.70	11.98	1.48	25.41	1.58	27.12
-5			0.62	10.64	1.35	23.17	1.45	24.89
-4			0.55	9.44	1.19	20.25	1.30	22.32
-3			0.55	9.44				
-2			0.48	8.24				
-1			0.50	8.58				
0			—	—				

INLET LINER

STATION	Erosion Depth	Erosion Rate	Char Depth	Char Rate
Throat-0	0.60	10.30	0.62	10.64
+1	0.51	8.75	0.63	10.81
+2	0.52	8.93	0.63	10.81
+3	0.48	8.24	0.58	9.95
+4	0.38	6.52	0.53	9.10
+5	0.38	6.52	0.55	9.44
+6	0.36	6.18	0.52	8.92
+7	0.34	5.83	0.58	9.96
+8	0.32	5.49	0.56	9.61
+9	0.26	4.46	0.47	8.07
+10	0.26	4.46	0.48	8.24
+11	0.28	4.80	0.43	7.38
+12	0.18	3.09	0.35	6.01
+13	-0.02	-0.34	0.18	3.09
+14	0.00	0.00	0.00	0.00
+15				

THROAT ASSEMBLY

STATION	Erosion Depth	Erosion Rate mils/sec	Char Depth	Char Rate mils/sec
-3	0.70	11.98	0.94	16.13
-2	0.62	10.64	0.85	14.59
-1	0.60	10.30	0.85	14.59
0	0.56	9.54	0.83	14.24
+1	0.50	8.58	0.80	13.73
+2	0.42	7.21	0.72	12.36
+3	0.32	5.45	0.63	10.81
+4	0.29	4.93	0.64	10.98

EXIT CONE LINER

FORWARD EXIT / AFT EXIT

STATION	Erosion Depth	Erosion Rate mils/sec	Char Depth	Char Rate mils/sec
+5	0.38	6.50	0.55	9.44
+6	0.55	9.44	0.57	9.78
+7	0.72	12.36	0.75	12.87
+8	0.80	13.73	0.82	14.35
+9	0.88	15.11	0.92	15.79
+10	0.94	16.13	0.98	16.82
[illegible]	0.99	16.95	1.02	17.51
[illegible]	0.98	16.82	1.02	17.50
[illegible]	0.83	14.24	0.87	14.93
[illegible]	0.50	8.60	0.54	9.27
[illegible]	0.21	3.60	0.25	4.29
+26	0.27	4.63	—	—
[illegible]	—	—	0.31	5.32
[illegible]	0.20	3.43	0.25	4.29
[illegible]	0.12	2.06	0.18	2.79
[illegible]	0.12	2.06	0.18	3.09
[illegible]	0.08	1.37	0.08	1.37
[illegible]	0.08	1.37	0.08	1.37

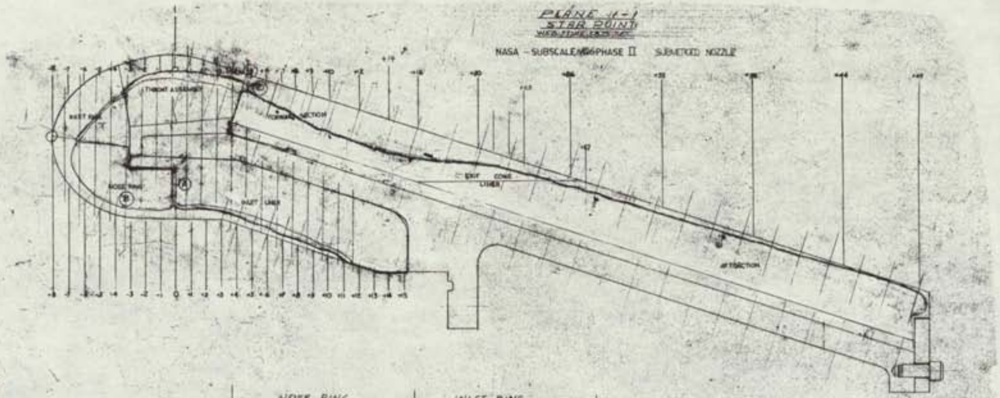
NOTE: 1. (-) INDICATES FINAL WALL THICKNESS IS LARGER THAN INITIAL WALL THICKNESS

2. ADDED STATIONS +14, +26 EXIT CONE

3. NOZZLE FABRICATION AND DISASSEMBLY CHANGES (B) (C) (D) AREAS NOTED ON TABLE OR SECTIONED PLANE 3-3

FIGURE 32

Figure 217. Nozzle No. 6 Erosion-Char Profile (Propellant Starpoint)



INLET LINER

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
THROAT 0	0.38	6.52	0.52	8.92
+1	0.32	5.49	0.45	7.72
+2	0.32	5.49	0.45	7.72
+3	0.25	4.29	0.35	6.06
+4	0.25	4.29	0.42	7.21
+5	0.22	3.77	0.40	6.86
+6	0.20	3.43	0.40	6.86
+7	0.15	2.57	0.38	6.23
+8	0.18	3.09	0.38	6.52
+9	0.12	2.06	0.30	5.15
+10	0.15	2.57	0.28	4.80
+11	0.05	0.86	0.15	2.57
+12	—	—	—	—
+13	—	—	—	—
+14	—	—	—	—
+15	—	—	—	—

NOSE RING

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
-8	CHAR LOST IN OVEN HEATER DURING DISASSEMBLY. COMBINED AS CHAR AFTER FIRING		0.72	14.05
-7			0.40	6.86
-6			0.33	5.68
-5			0.31	5.32
-4			0.30	5.14
-3			0.30	5.14
-2			0.30	5.14
-1			0.28	4.80
0			—	—

INLET RING

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
-8	0.79	13.54	0.91	15.60
-7	1.05	18.03	1.15	19.74
-6	1.05	18.03	1.13	19.40
-5	0.98	16.82	1.08	18.54
-4	0.92	15.75	1.01	17.35
-3	—	—	—	—

THROAT ASSEMBLY

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
-3	0.62	10.62	0.78	13.38
-2	0.55	9.44	0.75	12.87
-1	0.55	9.44	0.77	13.22
0	0.52	8.94	0.78	13.38
+1	0.50	8.58	0.80	13.73
+2	0.40	6.86	0.75	12.87
+3	0.33	5.68	0.65	11.18
+4	0.28	4.80	0.62	10.62

EXIT CONE LINER

FORWARD SECTION

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
+5	0.40	6.86	0.58	9.95
+6	0.60	10.30	0.61	10.47
+7	0.68	11.67	0.70	12.02
+8	0.72	12.36	0.75	12.80
+9	0.88	15.10	0.91	15.62
+10	1.00	17.06	1.02	17.51
+11	1.00	17.05	1.03	17.66
+14	1.06	18.20	1.08	18.52
+16	0.97	16.65	1.00	17.05
+18	0.53	9.09	0.53	9.09
+23	0.32	5.49	0.35	6.00
+26	0.29	4.98	—	—

AFT SECTION

STATION	EROSION DEPTH	EROSION RATE (MILS/SEC)	CHAR DEPTH	CHAR RATE (MILS/SEC)
+26	—	—	0.32	5.50
+32	0.25	4.29	0.30	5.15
+33	0.20	3.43	0.22	3.77
+38	0.16	2.75	0.18	3.09
+44	0.07	1.20	0.09	1.54
+49	0.08	1.37	0.11	[illegible]

FIGURE 31

NOTES - 1. ADDED STATIONS +14, +26 EXIT CONE
2. NOZZLE FABRICATION OR DISASSEMBLY CHANGES ARE NOTED IN SECTIONED PLANE 3-3

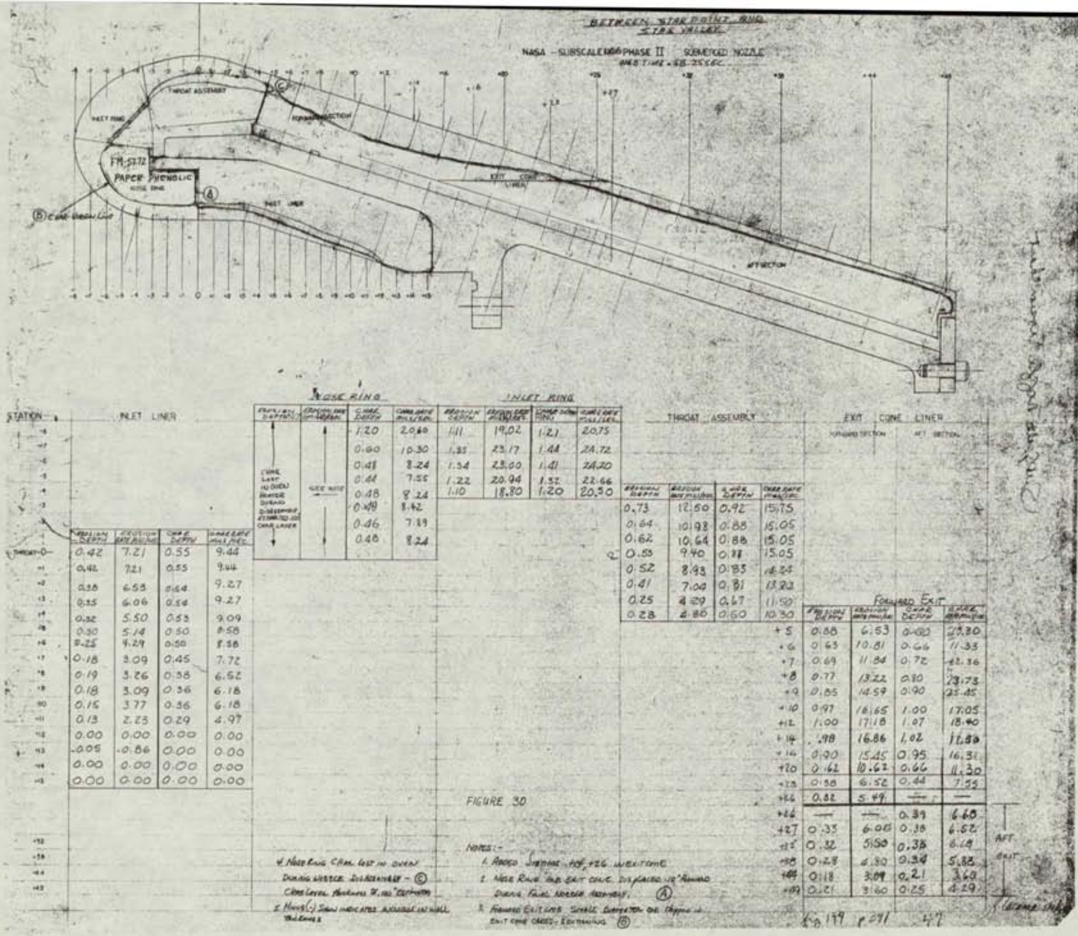
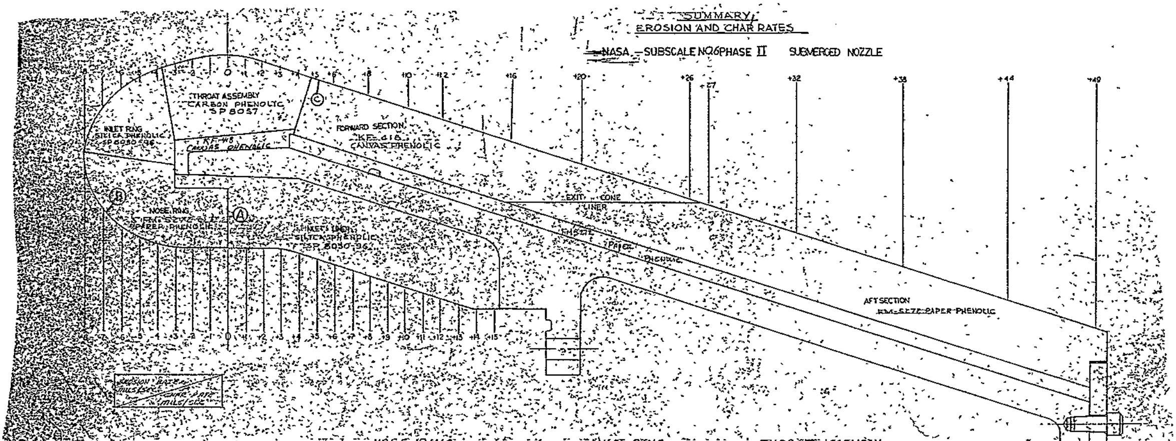


Figure 219. Nozzle No. 6 Erosion-Char Profile (Between Propellant Starpoint and Star Valley)



Values are given as erosion rate / char rate.

STATION	NOSE RING PLANE 1-1	NOSE RING PLANE 2-2	NOSE RING PLANE 3-3	INLET RING PLANE 1-1	INLET RING PLANE 2-2	INLET RING PLANE 3-3	THROAT ASSEMBLY PLANE 1-1	THROAT ASSEMBLY PLANE 2-2	THROAT ASSEMBLY PLANE 3-3
	CHAR DEPTH ONLY PLANE BASED / 14.05	SEE NOTE PLANE 1-1 / 26.60	SEE NOTE PLANE 1-1 / 20.60	13.54 / 15.60	22.80 / 25.41	19.02 / 20.75			
	— / 6.86	— / 17.10	— / 10.30	18.03 / 19.74	25.75 / 27.81	23.17 / 24.72			
	— / 5.68	— / 11.98	— / 8.24	18.03 / 19.40	25.41 / 27.12	23.00 / 24.20			
	— / 5.32	— / 10.64	— / 7.55	16.82 / 18.54	23.17 / 24.89	20.94 / 22.66			
	— / 5.14	— / 9.44	— / 8.24	15.75 / 17.35	20.25 / 22.32	18.80 / 20.50			
	— / 5.14	— / 9.44	— / 8.42	— / —	— / —	— / —	10.62 / 13.38	11.98 / 16.13	12.50 / 15.75
-2	— / 5.14	— / 8.24	— / 7.89				9.44 / 12.87	10.64 / 14.59	10.98 / 15.05
-1	— / 4.80	— / 8.58	— / 8.24				9.44 / 13.22	10.30 / 14.59	10.64 / 15.05
0	— / —	— / —	— / —				8.94 / 15.38	9.54 / 14.24	9.40 / 15.05
+1							8.58 / 13.73	8.58 / 13.73	8.93 / 14.24
+2							6.86 / 12.87	7.21 / 12.36	7.04 / 13.90
+3							5.68 / 11.18	5.45 / 10.81	4.29 / 11.50
+4							4.80 / 10.62	4.98 / 10.98	4.80 / 10.30

INLET LINER

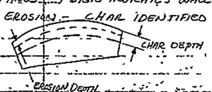
STATION	PLANE 1-1	PLANE 2-2	PLANE 3-3
[illegible]	6.52 / 8.92	10.30 / 10.64	7.21 / 9.44
[illegible]	5.49 / 7.72	8.75 / 10.81	7.21 / 9.44
[illegible]	5.49 / 7.72	8.93 / 10.81	6.53 / 9.27
[illegible]	4.29 / 6.06	8.24 / 9.95	6.06 / 9.27
[illegible]	4.29 / 7.21	6.52 / 9.10	5.50 / 9.09
[illegible]	3.77 / 6.86	6.52 / 9.41	5.14 / 8.58
[illegible]	3.43 / 6.86	6.18 / 8.92	4.29 / 8.58
[illegible]	2.57 / 6.23	5.83 / 9.96	3.09 / 7.72
[illegible]	3.09 / 6.52	5.49 / 9.61	3.26 / 6.52
[illegible]	2.06 / 5.15	4.46 / 8.07	3.09 / 6.18
[illegible]	2.57 / 4.80	4.46 / 8.64	3.77 / 6.18
[illegible]	0.86 / 2.57	4.80 / 7.38	2.23 / 4.97
+12	— / —	3.09 / 6.01	0.00 / 0.00
+13	— / —	-0.34 / 3.09	-0.86 / 0.00
[illegible]	— / —	0.00 / 0.00	0.00 / 0.00
+15	— / —	0.00 / 0.00	0.00 / 0.00

EXIT CONE LINER

STATION	FORWARD SECTION PLANE 1-1	FORWARD SECTION PLANE 2-2	FORWARD SECTION PLANE 3-3	AFT SECTION PLANE 1-1	AFT SECTION PLANE 2-2	AFT SECTION PLANE 3-3
+5	3.86 / 9.95	6.50 / 9.41	6.53 / 10.30			
+6	10.30 / 10.47	9.44 / 9.78	10.81 / 11.33			
+7	11.57 / 12.02	12.36 / 12.97	11.84 / 12.36			
+8	12.36 / 12.87	13.73 / 14.05	13.22 / 13.73			
+9	15.10 / 15.62	15.11 / 15.79	14.59 / 15.45			
+10	17.05 / 17.51	16.13 / 16.82	16.05 / 17.05			
+12	17.05 / 17.66	16.95 / 17.51	17.18 / 17.40			
+14	18.20 / 18.52	16.82 / 17.50	16.86 / 17.50			
+16	16.65 / 17.05	14.24 / 14.93	15.45 / 16.31			
+20	9.39 / 9.07	8.60 / 9.27	10.62 / 11.30			
+23	5.49 / 6.00	3.60 / 4.29	6.52 / 7.55			
+26	4.98 / —	4.63 / —	5.49 / —	— / 5.50	— / 5.32	— / 6.68
+27				4.29 / 5.14	3.43 / 4.[illegible]	6.86 / 6.52
+32				3.43 / 3.77	2.06 / 2.73	5.59 / 6.18
+38				2.78 / 3.09	2.06 / 3.03	4.92 / 5.83
+44				1.20 / 1.54	1.37 / 1.37	3.09 / 3.60
+49				1.37 / 1.88	1.37 / 1.37	3.60 / 4.29

NOTES:-

1. ADDED STATION +14, +26 (EXIT CONE)
2. SECTIONED PLANE IDENTIFICATION
   PLANE 1-1 ~ PROPELLANT STAR POINT
   PLANE 2-2 ~ PROPELLANT STAR VALLEY
   PLANE 3-3 ~ BETWEEN PROPELLANT STAR POINT & STAR VALLEY
3. MINUS (–) SIGN INDICATES WALL THICKNESS INCREASE
4. EROSION - CHAR IDENTIFIED.
5. NOZZLE FABRICATION OR DISASSEMBLY CHANGES Ⓐ, Ⓑ, Ⓒ ARE AS NOTED IN SECTIONED PLANE 3-3



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G. J. Wickham 5-5-69
R. Lacewell 5-7-69

Figure 220. Nozzle No. 6 Three Plane Erosion-Char Rate Summary

TABLE 49

NOZZLE NO. 6 POST-TEST INSPECTION

Ablative Liner	Comments
OD Submerged SP-8030-96 silica	Local delaminations Uniform erosion Good performance
Nose FM-5272 paper	Local high erosion Very weak char Local delamination and spalling Fair to good performance
Inlet SP-8030-96 silica	Local high erosion Structural integrity Good performance
Throat SP-8057 carbon	Uniform erosion Local delaminations and surface pitting Excellent performance
Forward Exit KF-418 canvas	Ply delamination High uniform erosion Irregular erosion surface Good performance
Aft Exit FM-5272 paper	Uniform erosion Irregular very weak char Local delaminations Good performance

Insulation Liner	Comments
Exit Cone Insulation FM-5272 paper	Local delaminations and cracks Adequate performance
Inlet-Throat Insulation KF-418 canvas	No delaminations Very satisfactory performance

TABLE 50

SUBSCALE MATERIAL COMPONENT PERFORMANCE RATING

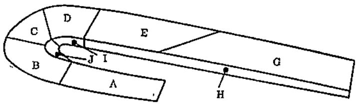
	Ablative Liners						Insulative Liners		Raw Material Cost
Material	Submerged Liner	Nose	Inlet	Throat	Forward Exit	Aft Exit	Exit Cone Insulation	Inlet Throat Insulation	($/lb)
Carbonaceous Tape Wrapped									
WB-8217 (Std)		Good (1)*	Excellent (1)						20.97
MX-4926 (Std)				Excellent (1)					19.00
SP-8050 (Std)				Excellent (3)	Excellent (1)				16.50
SP-8057		Good (3)	Very Good (3)	Excellent (6)	Very Good (3)				15.00
4C-1686		Good (2)	Good (2)						20.60
Molded									
LCCM-2626			Good (5)	Fair to Good (5) Very Good (2)					0.75
LCCM-2626X					Poor to Fair (5)** Fair (2)**	Fair (2)**			0.75
LCCM-4120						Good (5)			0.75
Low Carbonaceous or Non-Carbonaceous Tape Wrapped									
KF-418 Std Canvas	Good (5) Very Good (4)	Fair to Good (4)			Good (6)	Very Good (1)	Very Satisfactory (4)	Very Satisfactory (6)	1.50
FM-5272 Std Paper	Good (1)	Fair to Good (6)				Good (6)	Adequate (6)**	Adequate (3)**	2.00
23-RPD Asbestos Cork	Very Good (3)				Poor (4)**		Very Satisfactory (3)	Satisfactory (5) Very Satisfactory (2)	4.25
MXA-6012 Asbestos	Good (2)						Satisfactory (1)	Satisfactory (1)	1.85
SP-8030-96 Silica	Good (6)	Good (5)	Good (6) Fair to Good (4)	Good (4)		Very Good (3)		Very Satisfactory (4)	4.90
MXS-198 Silica						Good (4)			6.10
1581 - Glass MXB-6001							Very (2) Satisfactory (5)		2.82

*( ) indicates subscale test number.

**Nozzle material areas were eliminated as unacceptable.

TABLE 51

RECOMMENDED NOZZLE MATERIAL AREA LOCATION FOR 260 IN. NOZZLE



Ablative Liners						Insulation Liners		
Submerged Liner (A)	Nose (B)	Inlet (C)	Throat (D)	Forward Exit (E)	Aft Exit (G)	Exit Cone (H)	Throat (I)	Inlet (J)
1. FM-5272 paper	WB-8217 carbon	WB-8217 carbon	MX-4926 carbon	SP-8050 carbon	KF-418 canvas	MXB-6001 glass		23-RPD asbestos
2. MXA-6012 asbestos	4C-1686 carbon	4C-1686 carbon	LCCM-2626 graphite particle	SP-8057 carbon	SP-8030 silica	KF-418 canvas	KF-418 canvas	KF-418 canvas
3. 23-RPD asbestos	SP-8057 carbon	SP-8057 carbon	SP-8050 carbon	KF-418 asbestos	MXS-198 silica	23-RPD asbestos	23-RPD asbestos	MXA-6012 asbestos
4. KF-418 canvas	KF-418 canvas	SP-8030 silica	SP-8030 silica		LCCM-4120 graphite particle	MXA-6012 asbestos	MXA-6012 asbestos	SP-8030-96 silica
5. SP-8030-96 silica	FM-5272 paper	LCCM-2626 graphite particle	SP-8057 carbon		FM-5272 paper		SP-8030-96 silica	
6.	SP-8030 silica							

TABLE 52

COMPARISON OF MATERIAL PROPERTIES AND FABRICATION TECHNIQUES WITH MATERIAL TEST PERFORMANCE

Material	Fabrication Technique	Material Properties: Specific Gravity	Material Properties: Ult Compression[a]	Material Properties: Thermal Conductivity[b], k	Material Test Performance Erosion Rate (mils/sec)	Post-Test Structural Integrity
Throat Area (Silica and Carbonaceous Materials)					Station 0.0	
MX-4926 (Std) Carbon	Tape wrap - cured (225 psi - 300° F)	1.40	36,000	0.483	8.09	Very good
SP-8050 Carbon	Tape wrap - cured (225 psi - 300° F)	1.44	34,546	0.351	9.78	Excellent
LCCM-2626 Graphite particle	Molded - cured (1,000 psi - 325° F)	1.80	12,000	0.320	8.70	Very good, good
SP-8057 Carbon	Tape wrap - cured (225 psi - 320° F)	1.40	28,600	0.136	9.54	Excellent
SP-8030 Silica	Tape wrap - cured (225 psi - 310° F)	1.60	23,100	0.100	18.85	Excellent
OD Submerged Area (Silica, Asbestos, Canvas and Paper Materials)					Station +6.0	
SP-8030 Silica	Tape wrap - cured (225 psi - 310° F)	1.60	23,100	0.100	6.18	Good
KF-418 Canvas	Tape wrap - cured (225 psi - 300° F)	1.35	22,812	0.159	3.93/6.85	Excellent, excellent
23-RPD Asbestos	Tape wrap - cured (225 psi - 310° F)	1.50	15,500	0.069	4.98	Excellent
FM-5272 (Std) Paper	Tape wrap - cured (225 psi - 300° F)	1.34	24,370	0.230	2.46	Fair to good
MXA-6012 Asbestos	Tape wrap - cured (225 psi - 300° F)	1.61	22,219	0.077	5.22	Good
Aft Exit Cone (Silica, Canvas, Paper, and Carbonaceous Materials)					Station +32.0	
LCCM-2626X Graphite particle	Molded - cured (850 psi - 325° F)	NA	NA	NA	16.20	Fair
LCCM-4120 Graphite particle	Molded - cured (15 psi - 325° F)	1.50	8,200	0.886	0.68	Fair
SP-8030 Silica	Tape wrap - cured (225 psi - 310° F)	1.60	23,100	0.100	3.55	Very good
KF-418 (Std) Canvas	Tape wrap - cured (225 psi - 300° F)	1.35	22,812	0.159	1.75	Good
FM-5272 Paper	Tape wrap - cured (225 psi - 310° F)	1.34	24,370	0.230	5.58	Good
MXS-198 Silica	Tape wrap - cured (15 psi - 310° F)	1.50	34,600	NA	4.10	Very good

[a] With lamina warp direction or grain (psi) room temperature.

[b] Across lamina $\left(\frac{\text{Btu}}{\text{ft-hr-}^\circ\text{F}}\right)$ room temperature.

References: Materials screening section of this report.
AFRPL-TR-67-310 - "Evaluation of Low Cost Materials and Manufacturing Processes for Large Solid Rocket Motors"
AFML-TR-65-133 - "Thermal-Mechanical Properties of Five Ablative Reinforced Plastics from Room Temperature to 750° F"
AFRPL - Contract AF 04(611)-11417 - "Development of Castable Carbonaceous Materials for Solid Rocket Nozzles"

TABLE 53

SUMMARY OF FABRICATION CONDITIONS
TAPE WRAPPED COMPONENTS

	Material	Preheat Temperature (°F)	Head Pressure (lb/in.)	Billet Temperature (°F)	Stage	Maximum Cure Pressure (psi)	Maximum Cure Temperature (°F)
1.	SP-8030-96	100-125	240-300	100-110	No	225	310
2.	SP-8050	100-125	300	100-125	No	225	300
	MX-4926	100-125	300	100-125	No	225	320
	WB-8217	100-125	300	100-125	No	225	300
3.	SP-8057	225-275	200-300	125-155	No	225	300
4.	4C-1686	150-200	240-300	60-110	No	225	350
5.	23-RPD	150-200	160-240	40-50	Yes	225	310
6.	FM-5272	270-290	200-300	110-120	No	225	310
7.	KF-418	175-250	200-280	85-120	No	225	310
8.	MXA-6012	125-160	180-300	40-70	Yes	225	310
9.	MXS-198	80-120	200-300	80-110	No	13 (1 Atmosphere)	310

TABLE 54

MATERIAL PERFORMANCE AND PREDICTION ANALYSIS

1. Preliminary Material Selection

   Fourteen materials rated by erosion, char, specific gravity and cost/lb.

   Four 260 in. low cost material nozzle matrices of best ranked subscale materials.

2. Material Performance Graphs

   Thirteen materials erosion-char rates plotted vs subscale wall.
   Heat transfer coefficient (h/cp) or total wall flux (Q_T)

   Material design lines drawn.

3. Preliminary 260 in. Nozzle Design

   A standard material nozzle (computer designed).

   Aerodynamic flow analysis for h/cp and Q_T.

   Four low cost material nozzle matrices erosion (char rates predicted and scale factors calculated).

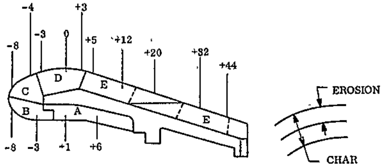
   Four low cost material nozzles computer designed, drawn, and weighted.

MATERIAL PERFORMANCE SUBSCALE NOZZLE
MAXIMUM EROSION-CHAR RATES (UNCORRECTED)

Material	Inlet Liner A +6	Inlet Liner A +1	Nose B -3	Nose B -8	Inlet C -8	Inlet C -4	Throat D -3	Throat D 0	Throat D +3	Exit Cone E +5 Forward	Exit Cone E +12 Forward	Exit Cone E +20 Forward Middle	Exit Cone E +32 Aft	Exit Cone E +44 Aft
1. Carbonaceous														
WB-8217 (Standard)			2.28 / 10.55	10.55 / 17.06	10.20 / 17.06	11.78 / 15.83								
MX-4926 (Standard)							9.32 / 14.95	8.09 / 14.95	4.75 / 13.02					
SP-8050 (Standard)							12.09 / 17.80	9.78 / 15.66	4.98 / 12.09	3.69 / 13.02	1.58 / 9.32	0.70 / 8.09		
LCCM-2626					17.14 / a	9.60 / a	8.87 / a	8.70 / a	6.96 / a					
LCCM-2626							11.31[b] / a	12.34[b] / a	15.42[b] / a					
LCCM-2626X										11.30[b] / a	15.50[b] / a	19.50[b] / a	16.20[b] / a	5.60[b] / a
LCCM-2626X										18.85 / a	Material Lost			
LCCM-4120												Material Lost	0.68 / a	0.34 / a
SP-8057			4.44 / 8.89	12.09 / 15.66	13.52 / 16.90	12.09 / 16.37	12.50 / 15.75	9.54 / 14.24	5.68 / 11.18	3.91 / 9.96	2.84 / 9.25	1.07 / 6.94		
4C-1686			9.74 / 12.70	8.70 / 17.40	8.70 / 15.48	9.92 / 19.50								
2. Low Carbonaceous Noncarbonaceous														
SP-8030-96	6.18 / 8.92	8.75 / 10.81			22.80 / 25.41	20.25 / 22.32								
SP-8030-96			10.79 / 12.85	19.71 / 22.28	31.96 / 33.77	23.93 / 24.75	20.98 / 22.13	18.85 / 20.16	13.93 / 16.23				3.55 / 6.76	1.42 / 5.69
KF-418 (Standard)	3.93 / 6.88	5.25 / 8.52												
KF-418 (Standard)	6.85 / 9.42	5.48 / 8.57	8.68 / 11.15	27.05 / 28.68						6.86 / 9.95	17.18 / 18.40	10.62 / 11.30	1.75 / 4.39	1.40 / 4.92
23-RPD	4.98 / 5.69	7.47 / 8.18								14.42 / 15.57	Material Lost	Material Lost		
FM-5272 (Standard)	2.46[c] / 5.27	2.81[c] / 6.68	d / 9.44	d / 26.60									5.50 / 6.18	3.09 / 3.60
MXA-6012	5.22 / 6.96	9.22 / 10.61												
MXS-198													4.10 / 8.19	0.82 / 6.55

[a]Char thickness cannot be seen.
[b]Indicates segmented ring.
[c]Char layer thickness estimated.
[d]Char lost in nozzle disassembly.

NOTES: 1. Input data for cost merit rating (CMR) index.
2. Erosion-char design curves.



Erosion Rate (mils/sec)
Char Rate (mils/sec)

TABLE 56

SUBMERGED LINER MATERIAL EVALUATION

Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1. SP-8030-96 Silica (Standard)	6	7.90	2.35	1.60	4.90	105	--
2. KF-418 Canvas	4, 5	6.00	2.86	1.35	1.50	24	2
3. 23-RPD Asbestos	3	6.13	0.72	1.50	4.25	56	4
4. FM-5272 Paper	1	2.64	3.34	1.34	2.00	22	1
5. MXA-6012	2	7.36	1.55	1.61	1.85	34	3

NOTES:

1. Erosion rate factor of safety = 1.25
   Char rate factor of safety = 1.50

2. Typical CMR index value calculation:

   $$\left[2.64\ (1.25) + (3.34)\ (1.50)\right]\ 1.34\ (2.00) = 22 \text{ CMR for FM-5272}$$

   Lowest CMR index number is best.

TABLE 57

NOSE MATERIAL EVALUATION

	Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1.	FM-5272 Paper	6	17.29	1.68	1.34	2.00	68	2
2.	KF-418 Canvas	4	21.27	1.95	1.35	1.50	63	1
3.	SP-8030-96 Silica	5	16.17	2.27	1.60	4.90	192	3
4.	4C-1686 Carbon	2	9.40	5.77	1.30	20.60	501	--
5.	SP-8057 Carbon	3	8.27	4.05	1.40	15.00	324	4
6.	WB-8217 Carbon (Standard)	1	6.42	7.39	1.42	20.97	482	--

NOTES:

1. Erosion rate factor of safety = 1.375
   Char rate factor of safety = 1.00

2. Assume paper char layer thickness (t = 0.10 in.)

3. Typical CMR index value calculation:

   $$\left[9.4\ (1.375) + 5.77\ (1.00)\right]\ 1.30\ (20.60) = 501 \text{ CMR for 4C-1686}$$

   Lowest CMR index number best.

TABLE 58

INLET MATERIAL EVALUATION

	Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1.	SP-8030-96 Silica	4, 6	28.05	1.77	1.60	4.90	344	2
2.	4C-1686 Carbon	2	9.14	8.10	1.30	20.60	584	4
3.	SP-8057 Carbon	3	12.80	3.87	1.40	15.00	484	3
4.	LCCM-2626 Graphite Particle	5	14.17	12.59	1.80	0.75	46	1
5.	WB-8217 Carbon (Standard)	1	10.99	5.45	1.42	20.97	653	--

NOTES:

1. Char thickness for LCCM-2626 was assumed to be 0.75 in. (from TU-622 test data).
2. Erosion rate factor of safety = 1.5
   Char rate factor of safety = 1.0
3. Typical CMR index value calculation:

   $$\left[12.80\ (1.50) + 3.87\ (1.00)\right]\ 1.40\ (15.00) = 484 \text{ CMR for SP-8057}$$

   Lowest CMR index number is best.

TABLE 59

THROAT MATERIAL EVALUATION

	Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1.	SP-8030-96 Silica	4	21.32	1.51	1.60	4.90	263	2
2.	SP-8057 Carbon	6	9.79	4.40	1.40	15.00	401	3
3.	LCCM-2626 Graphite Particle	2, 5	11.07	12.79	1.80	0.75	40	1
4.	SP-8050 Carbon	3	8.95	6.29	1.44	16.50	469	4
5.	MX-4926 Carbon (Standard)	1	7.38	6.92	1.40	23.00	579	--

NOTES:

1. Char thickness for LCCM-2626 was assumed to be 0.75 in. (based on TU-622 test data).
2. Erosion rate factor of safety = 1.50
   Char rate factor of safety = 1.00
3. Typical CMR index value calculation:

   $$\left[21.32\ (1.50) + 1.51\ (1.00)\right] 1.60\ (4.90) = 263 \text{ CMR for SP-8030}$$

   Lowest CMR index number is best.

TABLE 60

FORWARD EXIT MATERIAL EVALUATION

	Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1.	23-RPD Asbestos	4	Material Lost During Test				--	--[a]
2.	KF-418 Canvas	6	12.24	1.63	1.35	1.50	34	1
3.	SP-8057 Carbon	3	2.61	6.17	1.40	15.00	198	2
4.	LCCM-2626X Graphite Particle	5		Material Lost Locally During Test				--
5.	LCCM-2626X Graphite Particle	2	15.74	8.62[b]	1.80	0.75	38	--[a]
6.	SP-8050 Carbon (Standard)	1	1.99	8.15	1.44	16.50	253	3

[a] Material LCCM-2626X needs further processing development to be applied on this area.
[b] Char depth thickness was assumed to be 0.50 in. for LCCM-2626X.

NOTES:

1. Erosion rate factor of safety = 1.25
   Char rate factor of safety = 1.00
2. Typical CMR index value calculation:

$$\left[(12.24)\ 1.25 + 1.63\ (1.00)\right]\ 1.35\ (1.50) = 34 \text{ CMR for KF-418}$$

TABLE 61

AFT EXIT MATERIAL EVALUATION

	Material Tested	Motor No.	Average Corrected Erosion Rate (mils/sec)	Average Corrected Char Rate (mils/sec)	Specific Gravity ρ	Raw Material Cost ($/lb)	CMR Index	Rank
1.	MXS-198 Silica	4	2.93	4.66	1.50	6.10	76	4
2.	FM-5272 Paper	6	4.55	0.58	1.34	2.00	17	2
3.	KF-418 Canvas (Standard)	1	1.57	3.08	1.35	1.50	10	1
4.	SP-8030-96 Silica	3	2.48	3.83	1.60	4.90	54	3
5.	LCCM-4120 Graphite Particle	5	0.54	8.39[a]	1.50	0.75	10	1
6.	LCCM-2626X Graphite Particle	2	11.12	8.60[a]	1.80	0.75	30	--[b]

[a]Char depth thickness assumed to be 0.50 in. for LCCM-2626X and LCCM-4120.
[b]Material needs further improvement before it can be used for aft exit cone.

NOTES:

1. Erosion rate factor of safety = 1.25
   Char rate factor of safety = 1.00

2. Typical CMR index value calculation:

   $$\left[2.48\ (1.25) + 3.83\ (1.00)\right]\ (1.60)\ (4.90) = 54 \text{ CMR for SP-803-96}$$

   Lowest CMR index number is best.

TABLE 62

SUBSCALE MATERIAL COST RATING

Rating	Submerged Liner	Nose	Inlet	Throat	Forward Exit	Aft Exit
First	FM-5272 Paper	KF-418 Canvas	LCCM-2626 Graphite Particle	LCCM-2626 Graphite Particle	KF-418 Canvas	KF-418 Canvas LCCM-4120 Graphite Particle
Second	KF-418 Canvas	FM-5272 Paper	SP-8030-96 Silica	SP-8030-96 Silica	SP-8057 Carbon	FM-5272 Paper
Third	MXA-6012 Asbestos	SP-8030-96 Silica	SP-8057 Carbon	SP-8057 Carbon	SP-8050 Carbon	SP-8030-96 Silica
Fourth	23-RPD Asbestos	SP-8057 Carbon	4C-1686 Carbon	SP-8050 Carbon	a	MXS-198 Silica Epoxy Novolac

[a]Only three materials qualified.

TABLE 63

260 IN. FOUR NOZZLE ABLATIVE MATERIAL MATRIX

Low Cost Material Nozzle	Submerged Liner	Nose	Inlet	Throat	Forward Exit	Aft Exit
1	FM-5272 Paper (1)	WB-8217 Carbon	WB-8217 Carbon	MX-4926 Carbon	SP-8050 Carbon (3)	KF-418 Canvas (1)
2	KF-418 Canvas (2)	KF-418 Canvas (1)	LCCM-2626 Graphite Particle (1)	LCCM-2626 (1)	SP-8057 Carbon (2)	LCCM-4120 Graphite Particle (1)
3	23-RPD Asbestos (3)	FM-5272 Paper (2)	SP-8030-96 Silica (2)	SP-8030-96 Silica (2)	KF-418 Canvas (1)	FM-5272 Paper (2)
4	MXA-6012 Asbestos (4)	SP-8057 Carbon (3)	SP-8057 Carbon (3)	SP-8050 Carbon (4)	SP-8050 Carbon (3)	MXS-198 Silica (4)

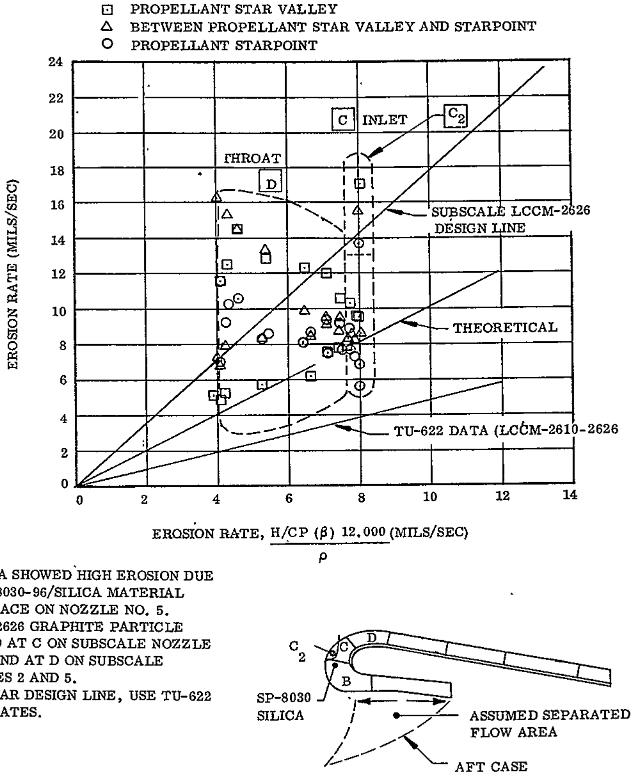
NOTE: Numbers in parentheses indicate subscale material cost rating

TABLE 64

INSULATIVE LINER EVALUATION

Subscale Nozzle Material	(lb/cu in.)	x	($/lb)	=	(CR)	Rank
	Exit Cone Backup Insulation					
1581 glass phenolic MXB-6001	0.073		3.50		0.26	4
KF-418 canvas phenolic	0.049		1.50		0.07	1
23-RPD asbestos phenolic	0.054		4.25		0.23	3
MXA-6012 asbestos phenolic	0.058		1.85		0.11	2
FM-5272 paper phenolic	0.048		2.00		0.10	a
	Throat-Inlet Insulation					
KF-418 canvas phenolic	0.049		1.50		0.07	1
23-RPD asbestos phenolic	0.054		4.25		0.23	3
MX-6012 asbestos phenolic	0.058		1.85		0.11	2
SP-8030-96 silica phenolic	0.057		4.90		0.28	4
FM-5272 paper phenolic	0.048		2.00		0.10	a

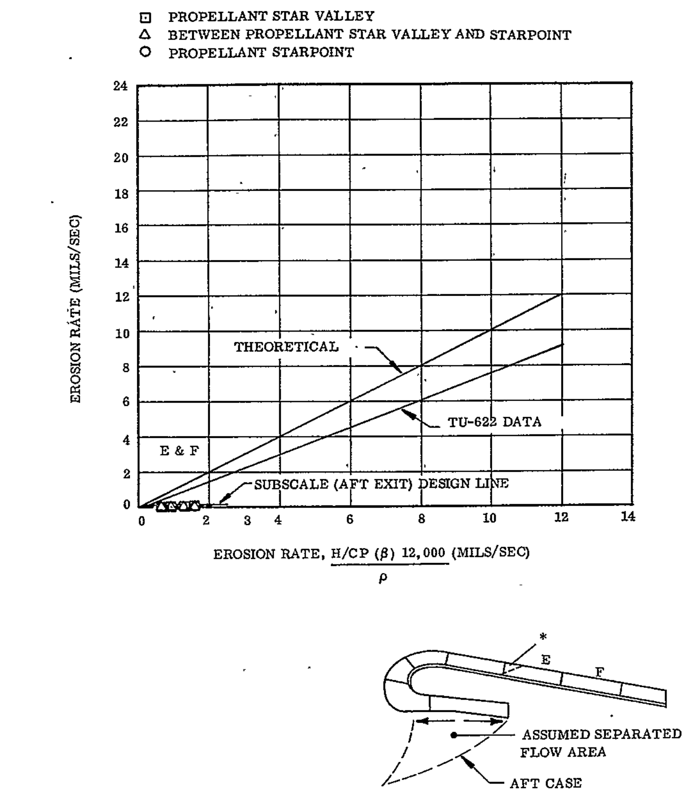
[a]Material eliminated from consideration because of only adequate structural integrity.



NOTES

1. C_2 DATA SHOWED HIGH EROSION DUE TO SP-8030-96/SILICA MATERIAL INTERFACE ON NOZZLE NO. 5.
2. LCCM-2626 GRAPHITE PARTICLE TESTED AT C ON SUBSCALE NOZZLE NO. 5 AND AT D ON SUBSCALE NOZZLES 2 AND 5.
3. FOR CHAR DESIGN LINE, USE TU-622 CHAR RATES.

Figure 221. LCCM-2626 Erosion Performance Curve



NOTES:
1. *THIS AREA WAS NOT PLOTTED BECAUSE IT WAS NEXT TO LCCM-2626X WHICH ERODED OUT IN THE FORWARD EXIT CONE.
2. LCCM-4120 GRAPHITE PARTICLE WAS TESTED IN SUBSCALE NOZZLE NO. 5.
3. TU-622 CHAR RATES SHOULD BE USED FOR CHAR DESIGN LINE.

24535-82

Figure 222. LCCM-4120 Erosion Performance Curve

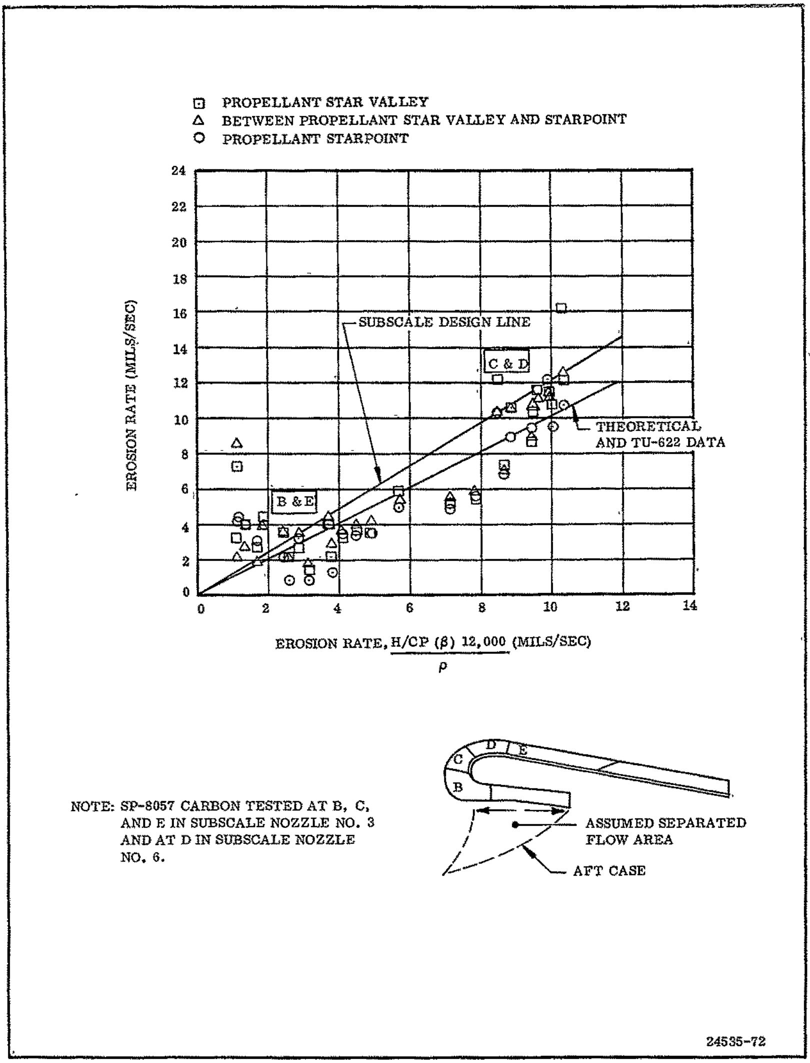
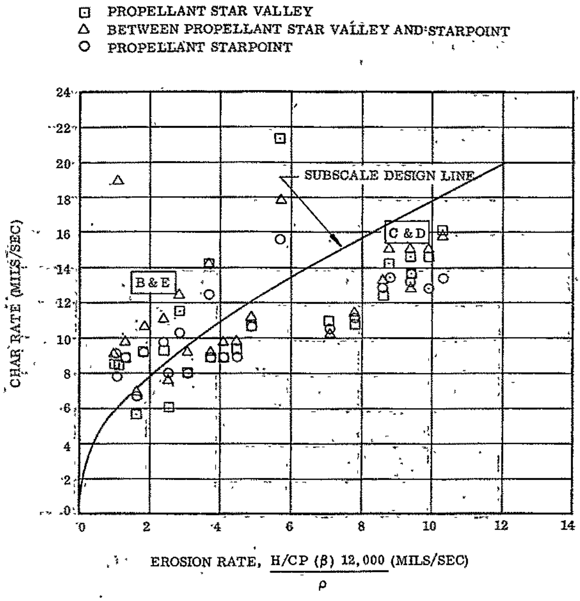
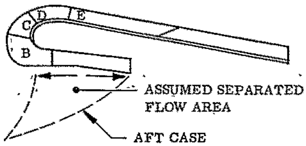


Figure 223. SP-8057 Erosion Performance Curve

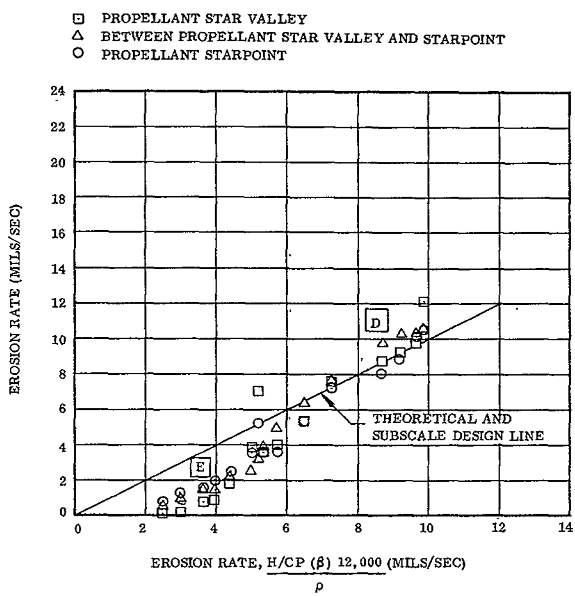


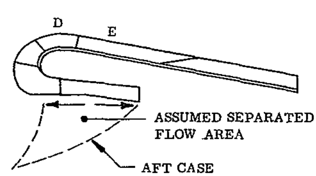


NOTE: SP-8057 CARBON TESTED AT B, C, AND E IN SUBSCALE NOZZLE NO. 3 AND AT D IN SUBSCALE NOZZLE NO. 6.

24535-78

Figure 2.24. SP-8057 Char Performance Curve





NOTE: SP-8050 CARBON TESTED AT D IN SUBSCALE NOZZLE NO. 3 AND AT E IN SUBSCALE NOZZLE NO. 1.

24535-87

Figure 225. SP-8050 Erosion Performance Curve

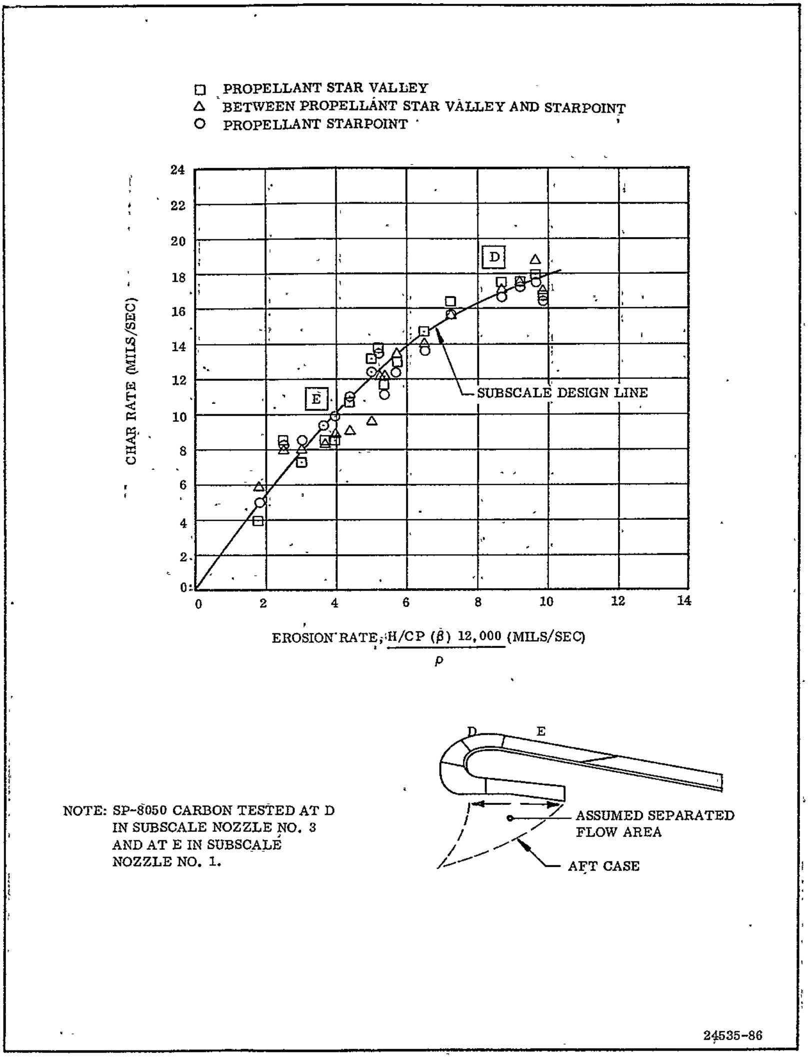


Figure 226. SP-8050 Char Performance Curve

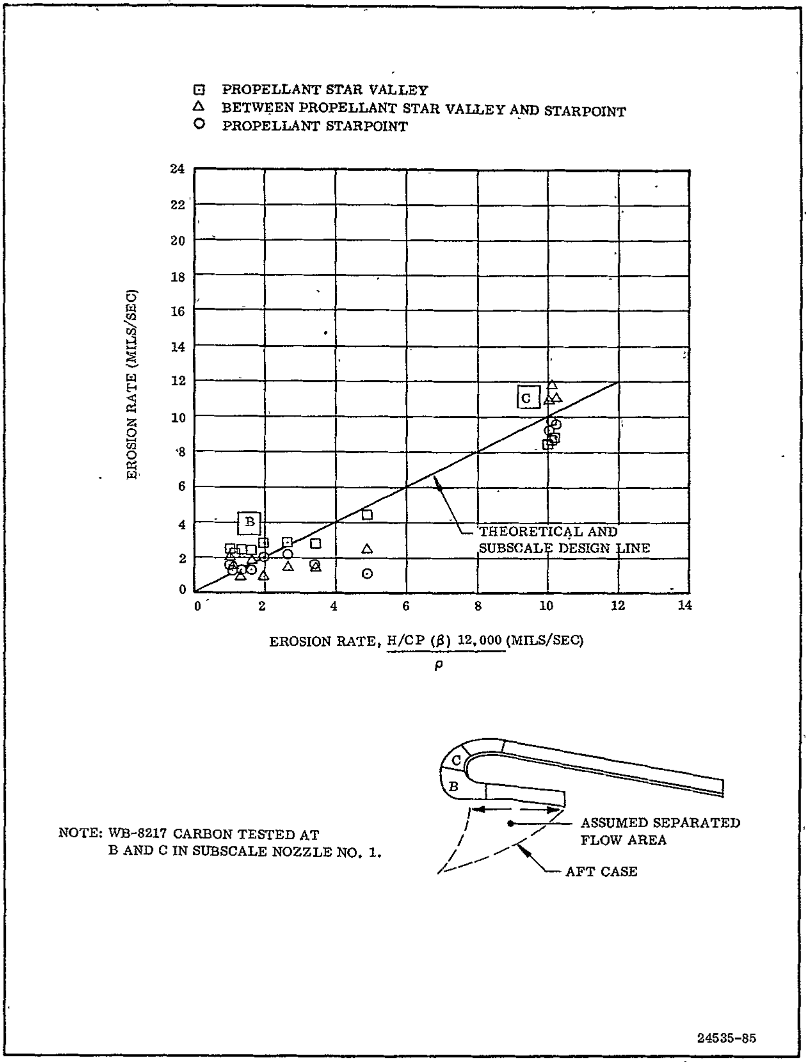


Figure 227. WB-8217 Erosion Performance Curve

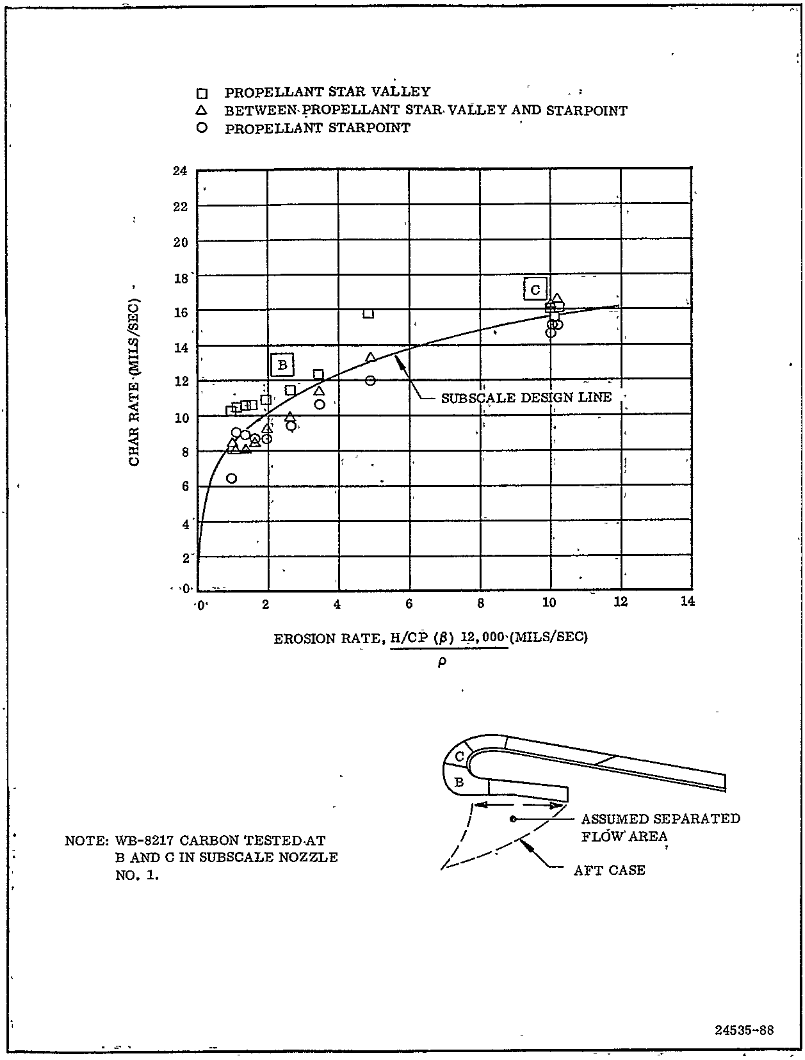
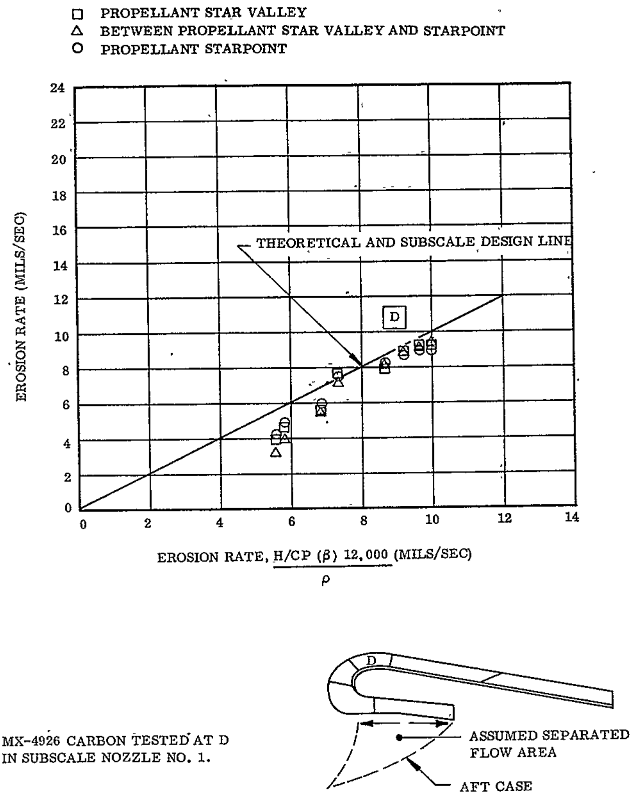


Figure 228. WB-8217 Char Performance Curve



NOTE: MX-4926 CARBON TESTED AT D IN SUBSCALE NOZZLE NO. 1.

24535-91

Figure 229. MX-4926 Erosion Performance Curve.

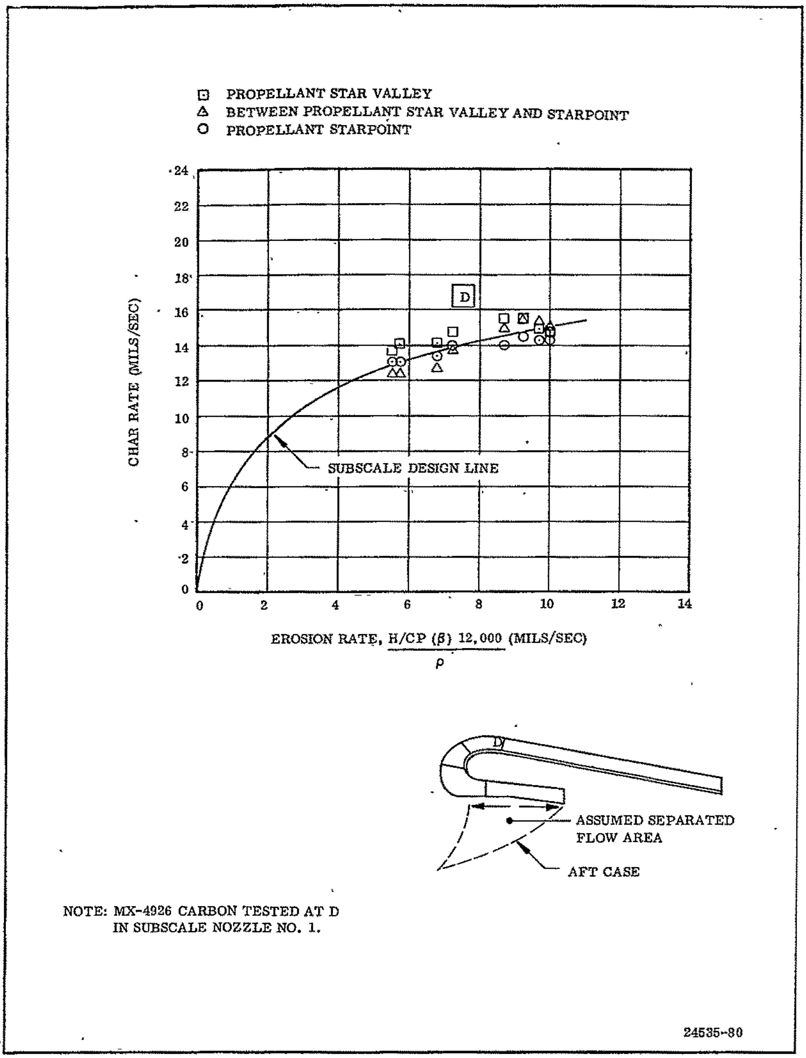


Figure 230. MX-4926 Char Performance Curve

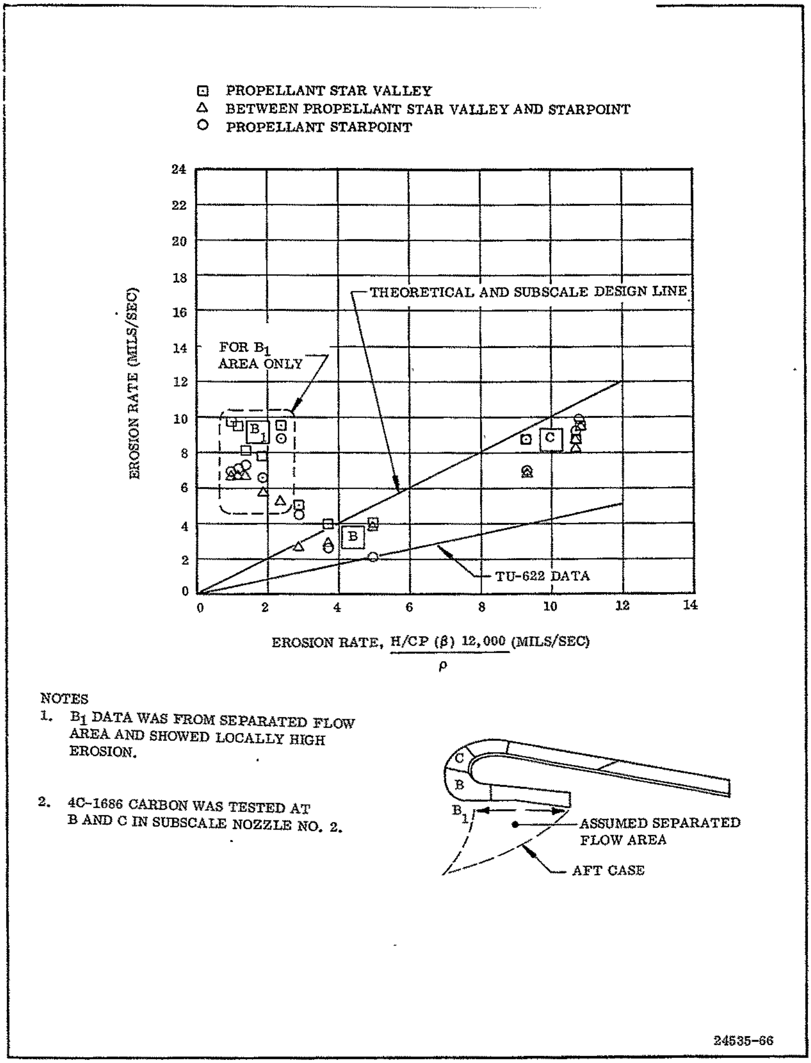
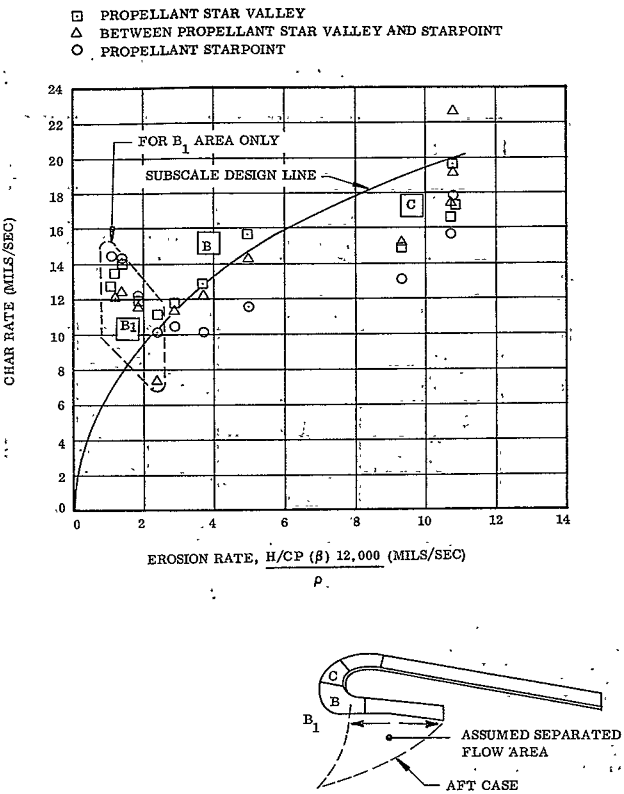


Figure 231. 4C-1686 Erosion Performance Curve

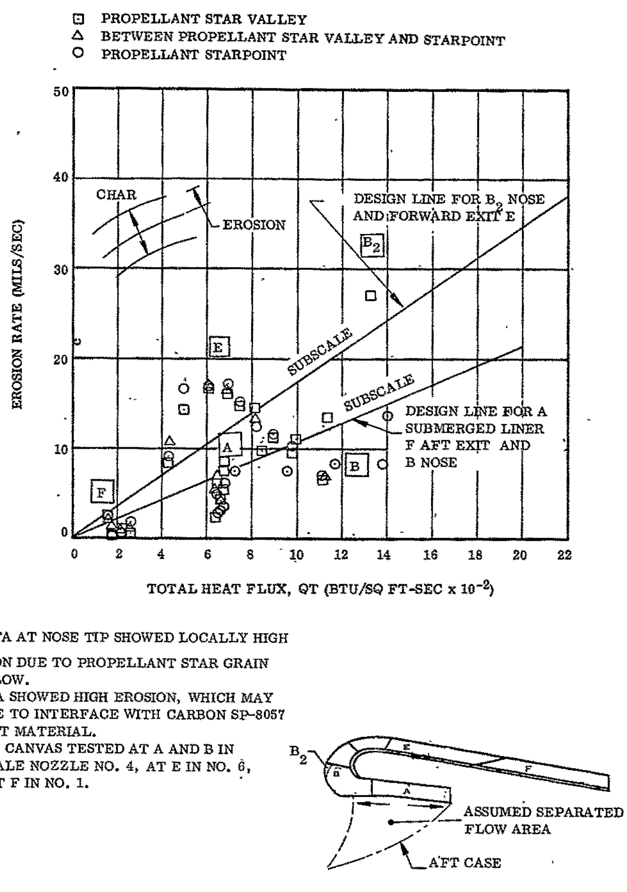


NOTES:

1. B_1 DATA WAS FROM SEPARATED FLOW AREA AND SHOWED LOCALLY HIGH EROSION.
2. HC-1686 CARBON WAS TESTED AT B AND C IN SUBSCALE NOZZLE NO. 2.

24535-81

Figure 232. 4C-1686 Char Performance Curve

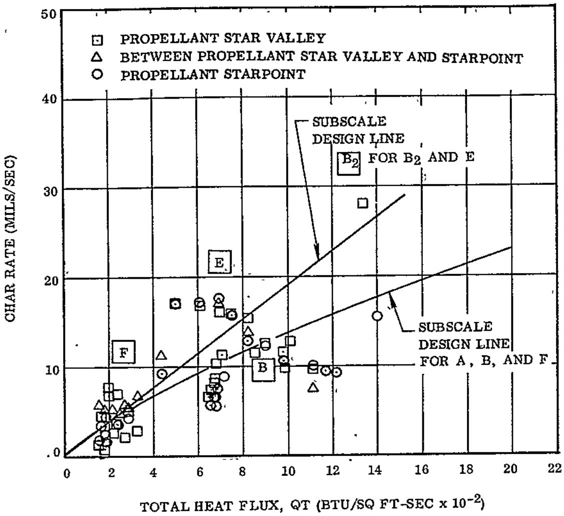


NOTES:

1. B_2 DATA AT NOSE TIP SHOWED LOCALLY HIGH EROSION DUE TO PROPELLANT STAR GRAIN GAS FLOW.
2. E DATA SHOWED HIGH EROSION, WHICH MAY BE DUE TO INTERFACE WITH CARBON SP-8057 THROAT MATERIAL.
3. KF-418 CANVAS TESTED AT A AND B IN SUBSCALE NOZZLE NO. 4, AT E IN NO. 6, AND AT F IN NO. 1.

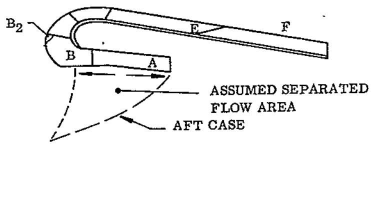
24535-94

Figure 233. KF-418 Erosion Performance Curve



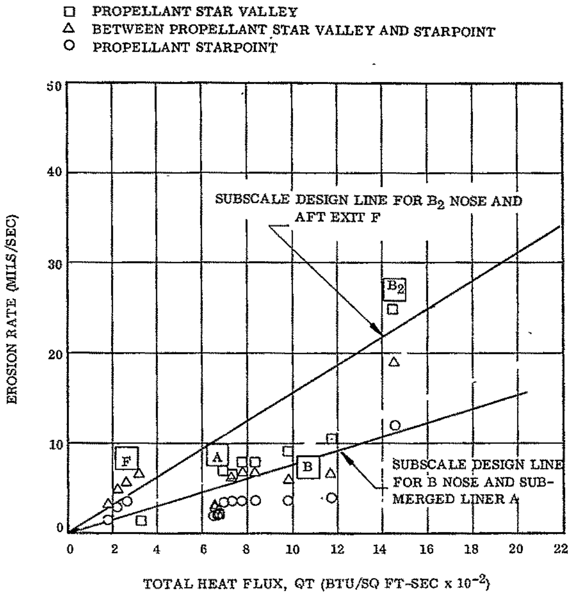
NOTES:

1. B_2 DATA AT NOSE TIP SHOWED LOCALLY HIGH EROSION DUE TO PROPELLANT STAR GRAIN GAS FLOW.
2. E DATA SHOWED HIGH EROSION, WHICH MAY BE DUE TO INTERFACE WITH SP-8057 CARBON THROAT.
3. KF-418 TESTED AT A AND B IN SUBSCALE NOZZLE NO. 4, AT E IN NO. 6, AND AT F IN NO. 1.



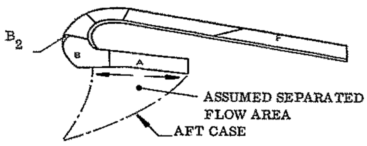
24535-83

Figure 234. KF-418 Char Performance Curve



NOTES:

1. B_2 DATA AT NOSE TIP SHOWED HIGH LOCAL EROSION DUE TO PROPELLANT STAR GRAIN GAS FLOW.
2. FM-5272 PAPER TESTED AT A IN SUBSCALE NO. 1 AND AT B AND F IN SUBSCALE NO. 6.



24535-92

Figure 235. FM-5272 Erosion Performance Curve

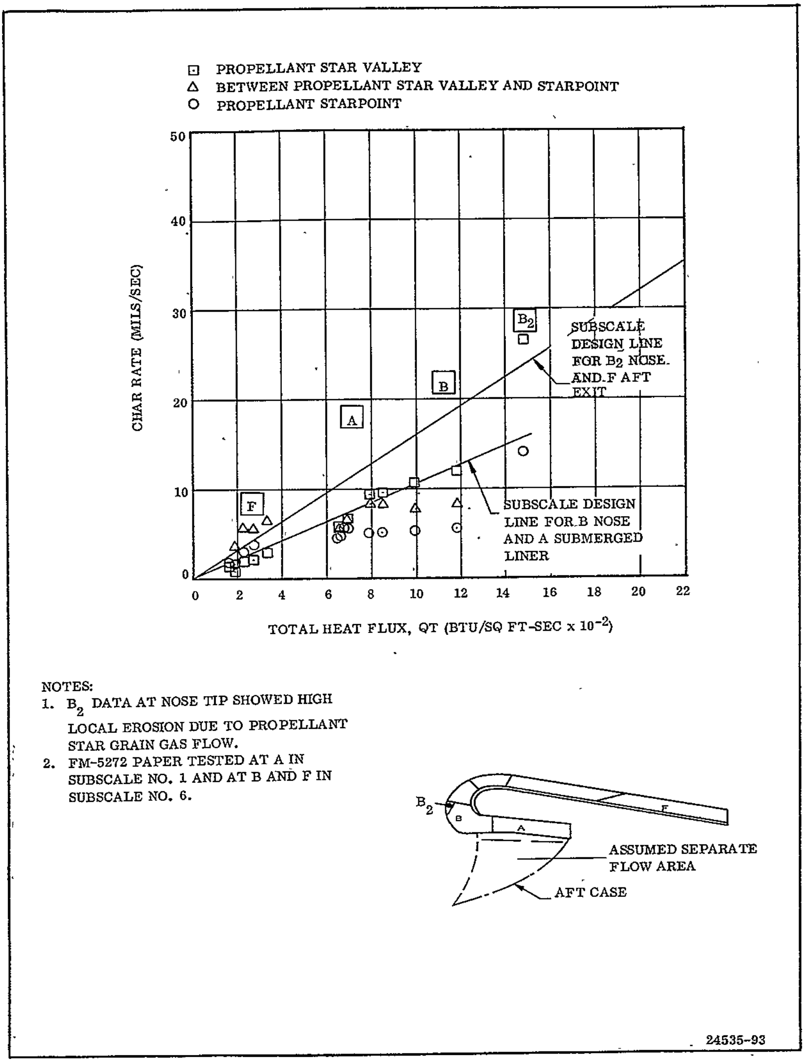
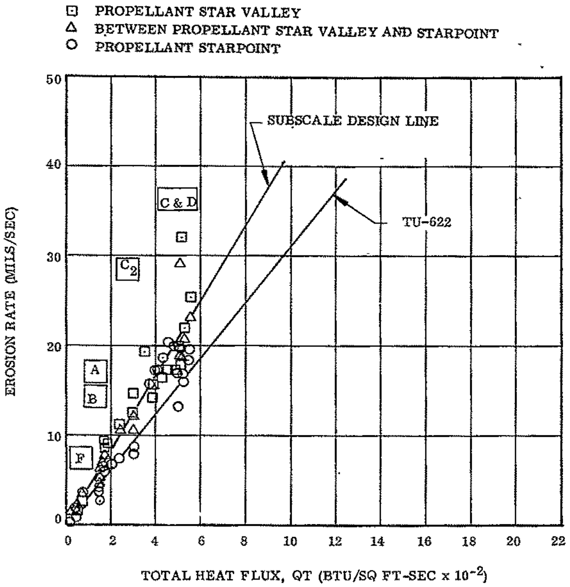


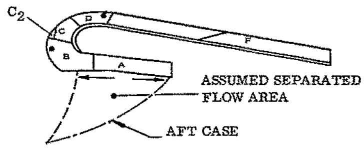
Figure 236. FM-5272 Char Performance Curve



NOTES

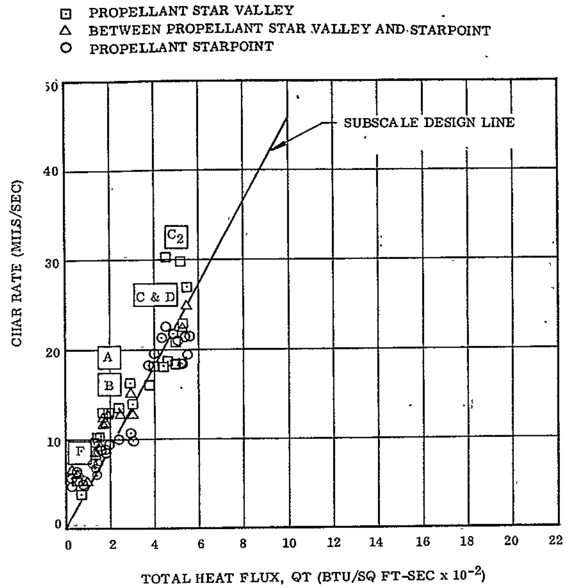
1. C_2 DATA AT INLET SHOWED LOCAL HIGH EROSION ON ONE TEST DUE TO PROPELLANT STAR GRAIN GAS FLOW.

2. SP-8030-96 SILICA TESTED AT A IN SUBSCALE NO. 6, AT B IN SUBSCALE NO. 5, AT C IN SUBSCALE NO. 4 AND 6, AT D IN SUBSCALE NO. 4, AND AT F IN SUBSCALE NO. 3.



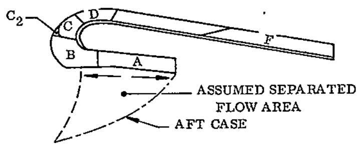
24535-95

Figure 237. SP-8030-96 Erosion Performance Curve



NOTES:

1. C_2 DATA AT INLET SHOWED LOCAL HIGH EROSION DUE TO PROPELLANT STAR GRAIN GAS FLOW.
2. SP-8030-96 SILICA WAS TESTED AT A IN SUBSCALE NO. 6, AT B IN SUBSCALE NO. 5, AT C IN SUBSCALE NO. 4 AND 6, AT D IN SUBSCALE NO. 4, AND AT F IN SUBSCALE NO. 3.



24535-97

Figure 238. SP-8030-96 Char Performance Curve

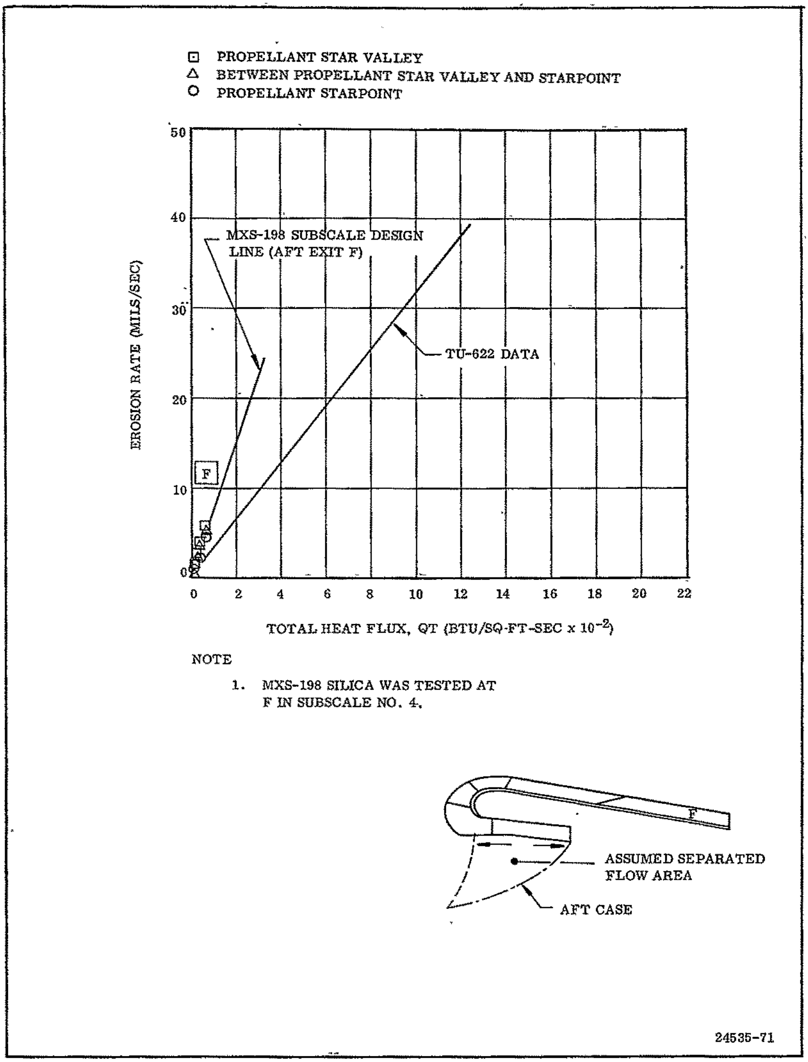


Figure 239. MXS-198 Erosion Performance Curve

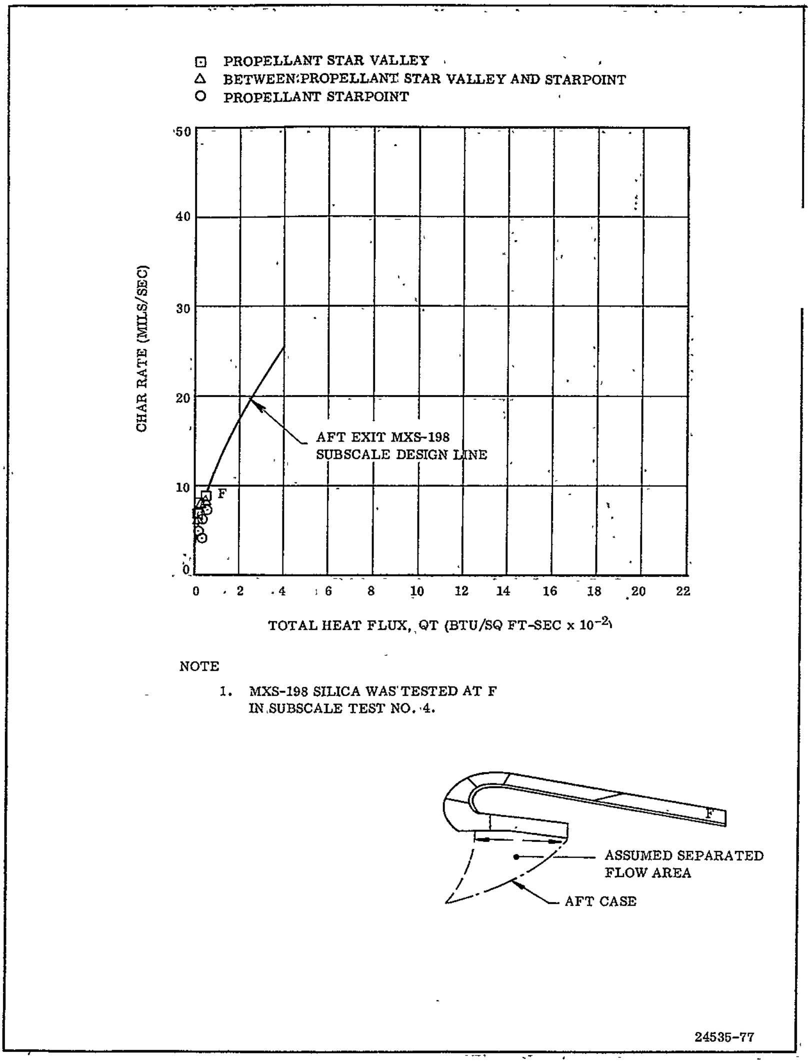
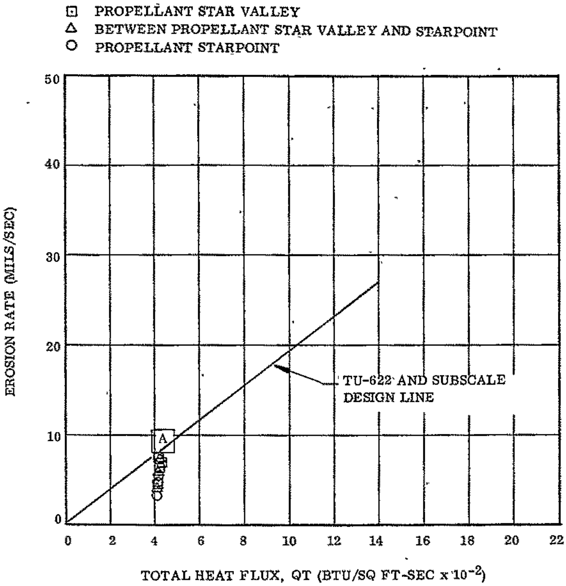
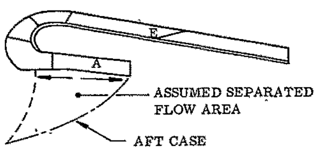


Figure 240. MXS-198 Char Performance Curve.



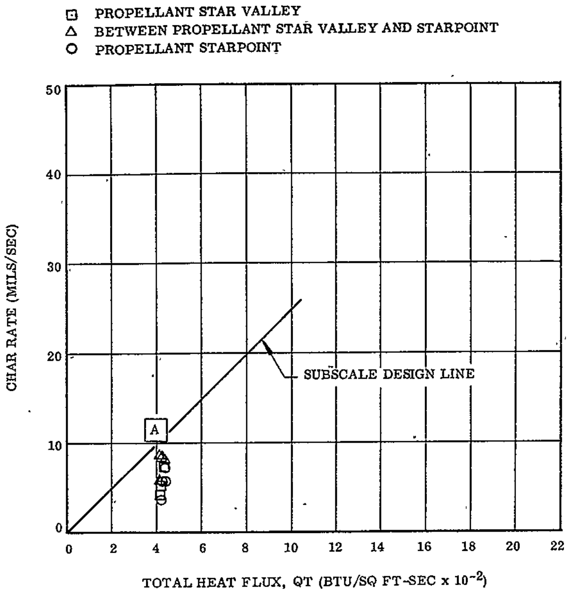
NOTES

1. E DATA WAS NOT PLOTTED BECAUSE IT DID NOT SURVIVE MOTOR FIRING.
2. 23-RPD ASBESTOS WAS TESTED AT A IN SUBSCALE TEST NO. 3 AND AT E IN SUBSCALE NO. 4.

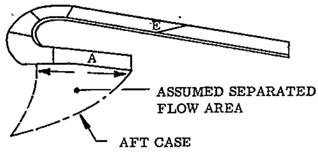


24535-73

Figure 241. 23-RPD Erosion Performance Curve

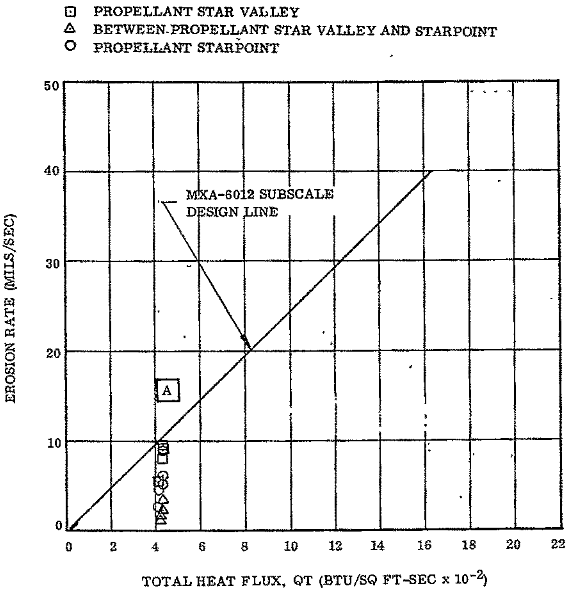


NOTES
1. E DATA IN THIS REGION WAS NOT PLOTTED BECAUSE IT DID NOT SURVIVE MOTOR FIRING.
2. 23-RPD ASBESTOS WAS TESTED AT A IN SUBSCALE NO. 3 AND AT E IN SUBSCALE NO. 4.



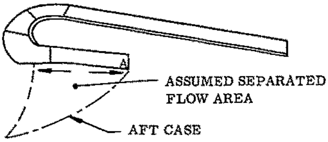
24535-74

Figure 242. 23-RPD Char Performance Curve



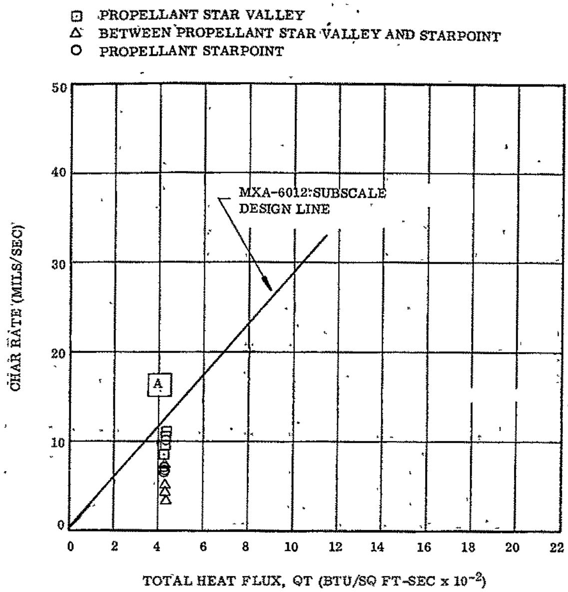
NOTE

1. MXA-6012 ASBESTOS TESTED AT A IN SUBSCALE NO. 2.



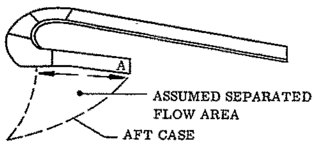
24535-89

Figure 243. MXA-6012 Erosion Performance Curve



NOTE

1. MXA-6012 ASBESTOS TESTED AT A IN SUBSCALE TEST NO. 2.



24535-90

Figure 244. MXA-6012 Char Performance Curve

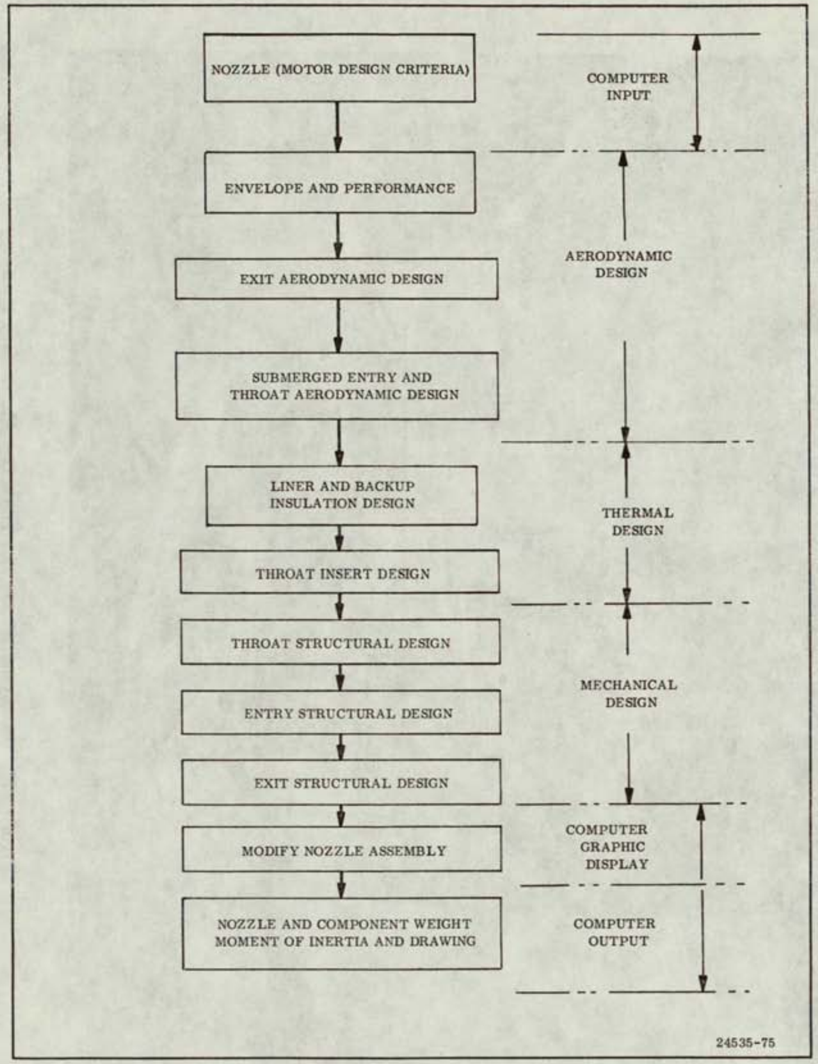


Figure 245. Major Computer Subroutines and Flow Path

Figure 246. Modifying Nozzle Design on Graphic Display Console

TABLE 65

COMPUTER OUTPUT, LINER THICKNESS DESIGN

BASE

NOZZLE INSULATION DESIGN (PAGE 1) INSULATION STATION TABLE

BDST	INST	EPS	X	R	M	PS	FSE	MOD	XDOT	TLE	FSC	TLC	TLV	TL	TBU	A	TBM	TB	TTOT	L	NO.
1		1.429	21.046	53.260	0.467	522.92	1.25	1.00	0.0	0.0	1.00	0.700	0.0	0.700	0.060		0.0	0.060	0.760	L	126
2UP		1.204	7.062	48.883	0.597	483.09	1.25	1.00	0.0	0.0	1.00	0.700	0.0	0.700	0.060	0	0.0	0.060	0.760	L	180
3DN		1.251	7.062	49.820	0.562	494.16	1.25	1.00	0.0	0.0	1.00	0.861	0.0	0.861	0.060		0.0	0.060	0.921	L	270
4UP		2.103	-35.000	64.600	0.296	564.20	1.50	1.00	3.20	0.446	1.00	0.861	0.395	1.702	0.060		0.0	0.060	1.762	L	324
4DN(NOSE)		2.103	-35.000	64.600	0.296	564.20	1.50	1.00	3.20	0.446	1.00	1.033	0.223	1.702	0.257		0.0	0.257	1.960	L	342
5UP		1.124	-17.500	47.236	0.672	457.57	1.50	1.00	7.25	1.010	1.00	1.033	0.505	2.548	0.257	1	0.058	0.315	2.863	L	360
5DN		1.124	-17.500	47.236	0.672	457.57	1.50	1.00	7.25	1.010	1.00	1.033	0.505	2.548	0.315	1	0.0	0.315	2.863	L	378
6(THROAT)		1.000	0.0	44.550	1.000	337.63	1.50	1.00	8.28	1.153	1.00	0.968	0.576	2.697	0.315		0.0	0.315	3.013	L	414
7UP		1.056	8.038	45.787	1.258	248.27	1.50	1.00	5.29	0.737	1.00	0.964	0.369	2.071	0.315	1	0.0	0.315	2.386	L	450
7DN		1.056	8.038	45.787	1.258	248.27	1.25	1.00	5.29	0.737	1.00	0.964	0.184	1.886	0.257	1	0.242	0.500	2.386	L	468
	7.1	1.124	12.632	47.236	1.385	208.98	1.25	1.00	5.03	0.700	1.00	0.960	0.175	1.835	0.257		0.0	0.257	2.093	L	486
	7.2	1.192	17.090	48.641	1.480	182.59	1.25	1.00	4.79	0.667	1.00	0.956	0.167	1.790	0.257		0.0	0.257	2.047	L	504
8UP		1.260	21.422	50.007	1.558	162.69	1.25	1.00	4.58	0.638	1.00	0.951	0.159	1.748	0.257	1	0.000	0.257	2.006	L	522
8DN		1.260	21.422	50.007	1.558	162.69	1.25	1.00	4.58	0.638	1.00	0.951	0.159	1.748	0.257	1	0.0	0.257	2.006	L	540
	8.1	2.297	76.948	67.514	2.160	59.62	1.25	1.00	2.93	0.408	1.00	0.885	0.102	1.395	0.257		0.0	0.257	1.653	L	558
	8.2	3.333	120.787	81.337	2.455	34.69	1.25	1.00	2.32	0.324	1.00	0.822	0.081	1.227	0.257		0.0	0.257	1.484	L	576
14UP		4.370	158.189	93.130	2.654	23.78	1.25	1.00	2.01	0.280	1.00	0.763	0.070	1.113	0.257	1	0.0	0.257	1.370	L	594
14DN		4.370	158.189	93.130	2.654	23.78	1.25	1.00	3.09	0.430	1.00	0.380	0.108	0.918	0.257	1	0.194	0.452	1.370	L	612
	14.1	6.580	225.261	114.277	2.940	13.67	1.25	1.00	0.97	0.136	1.00	0.305	0.034	0.475	0.257		0.0	0.257	0.732	L	630
	14.2	8.790	281.724	132.081	3.136	9.32	1.25	1.00	0.0	0.0	1.00	0.244	0.0	0.244	0.257		0.0	0.257	0.502	L	648
15(EXIT)		11.000	331.440	147.756	3.285	6.95	1.25	1.00	0.0	0.0	1.00	0.195	0.0	0.195	0.257		0.0	0.257	0.452	L	666
	SL	1.254	21.046	45.889	1.551	164.25	1.25	1.00	4.60	0.640	1.00	0.952	0.160	1.752	0.257		0.0	0.257	2.009	L	684

DEFINITION OF SYMBOLS

BDST	BOUNDARY STATION SYMBOL	FSC	FACTOR OF SAFETY,CHAR
INST	INTERMEDIATE STATION SYMBOL	TLC	CHARRED LINER THICKNESS (IN)
EPS	EXPANSION RATIO AT STATION	TLV	VIRGIN LINER THICKNESS AT END OF FIRING (IN)
X	AXIAL DISTANCE DOWNSTREAM OF THROAT (IN)	TL	TOTAL LINER THICKNESS AT IGNITION, TLE + TLC + TLV,(IN)
R	RADIUS FROM AXIS (IN)	TBU	REQUIRED BACKUP INSULATION THICKNESS (IN)
M	MACH NUMBER	A	BOUNDARY MATCH FLAG (1 REQUIRES MATCHING OF TTOT ON EACH SIDE)
PS	STATIC PRESSURE	TBM	EXTRA BACKUP NECESSARY FOR MATCH OF TTOT (IN)
FSE	FACTOR OF SAFETY, EROSION	TB	TOTAL BACKUP THICKNESS, TBU + TBM, (IN)
MOD	EROSION RATE MULTIPLIER	TTOT	TOTAL OF LINER AND BACKUP THICKNESSES, TL + TB, (IN)
XDOT	EROSION RATE OF LINER (MILS PER SEC)	LNO	L NUMBER OF EPS , NUMBERS ARE SEQUENTIAL FROM LEFT TO RIGHT
TLE	ERODED LINER THICKNESS (IN)	SL	SPLITLINE,FLANGE,OR INJECTOR STATION IN EXIT

SOME VALUES IN TABLE ARE NOT OPTIONAL INPUT,SEE DIAGRAM IN USERS MANUAL FOR THIS NOZZLE DESIGNATOR

NOTE-- IF XDOT IS INPUT AT THROAT,XDOT AT EACH STATION WILL CHANGE BY THE RATIO (XDOT THROAT INPUT/XDOT THROAT CALCULATED) EXCEPT AT STATIONS WHERE XDOT IS ALSO INPUT. USE MOD TO CHANGE THROAT XDOT ONLY.

TABLE 66

COMPUTER OUTPUT, LINER WEIGHT

BASE

NOZZLE INSULATION DESIGN (PAGE 2) MATERIALS,WEIGHT SUMMARY, AND THROAT INSERT GEOMETRY
MATERIAL IDENTIFICATION AND WEIGHT OF INSULATION SECTIONS BETWEEN STATIONS

SECTION	LINER MATERIAL CODE	LINER WEIGHT LB	BACKUP MATERIAL CODE	BACKUP WEIGHT LB	TOTAL SECTION WEIGHT	L NUMBER OF LINER CODE
1-2UP	2	206.55	3	0.0	206.55	L 702
3DN-4UP	7	1105.90	3	0.0	1105.90	L 717
4DN-5UP	7	1776.72	3	1444.95	3221.68	L 727
5DN-7UP	7	1120.29	2	2293.65	3413.94	L 732
7DN-8UP	7	406.92	3	109.24	516.17	L 742
8DN-14UP	7	6161.72	3	1117.71	7279.43	L 747
14DN-15	2	4611.22	3	3168.67	7779.89	L 752

MATERIAL CODES ARE IDENTIFIED IN INSULATION MATERIALS TABLE AT BOTTOM OF PAGE

INSULATION MATERIALS

CODE	NAME	VIRGIN DENSITY (LB/IN**3)	CHAR DENSITY (LB/IN**3)	L NUMBER OF VIR. DENS.
1	GRAPHITE CLOTH PHENOLIC	0.0521	0.0376	L 757
2	SILICA CLOTH PHENOLIC	0.0632	0.0509	L 759
3	GLASS CLOTH PHENOLIC	0.0660	0.0538	L 761
4	HIGH DENSITY GRAPHITE	0.0686	0.0	L 763
5	PYROLYTIC GRAPHITE	0.0777	0.0	L 765
6	TUNGSTEN	0.6980	0.0	L 767
7	CARBON CLOTH PHENOLIC	0.0521	0.0376	L 769
8	ASBESTOS CLOTH PHENOLIC	0.0637	0.0509	L 771
9	FILLED BUNA RUBBER	0.0464	0.0230	L 773
10	FIBROUS GRAPHITIC COMPOSITE	0.0506	0.0	L 775
11	POROUS TUNGSTEN	0.5584	0.0	L 777
12		0.0	0.0	L 779
13		0.0	0.0	L 781
14		0.0	0.0	L 783
15		0.0	0.0	L 785

L NUMBERS IN ALL THREE TABLES ARE CONSECUTIVE FROM LEFT TO RIGHT

TABLE 67

COMPUTER OUTPUT, STEEL STRUCTURE WEIGHTS

BASE

NOZZLE STRUCTURAL DESIGN (PAGE 1) RINGS, SHELLS, AND SPECIAL STATIONS

STRUCTURAL RINGS

	SAFETY FACTOR	MATERIAL CODE	X TO CENTROID (IN)	R TO CENTROID (IN)	AXIAL LENGTH (IN)	RADIAL THICKNESS (IN)	WEIGHT (LB)	MINIMUM THICKNESS (IN)	L NUMBER OF SAFETY FACTOR
FLANGE	1.25	2	21.768	53.842	1.844	2.757	486.59	0.30	L 787
FIXED EXTENSION	1.25	2	-5.090	48.575	24.320	0.648	1399.98	0.20	L 893

STRUCTURAL SHELLS

SHELL (STATION-TO-STATION)	SAFETY FACTOR	MATERIAL CODE	X, UPSTREAM END (IN)	X, DOWNSTREAM END (IN)	THICKNESS UPSTREAM (IN)	THICKNESS DOWNSTREAM (IN)	WEIGHT (LB)	MINIMUM THICKNESS (IN)	L NUMBER OF SAFETY FACTOR
WS 7-9	1.25	2	8.038	21.046	0.648	0.446	666.71	0.100	L 899
WS 9-12	1.25	2	21.046	176.243	0.236	0.219	4598.96	0.100	L 907
WS12-15	1.25	6	176.243	331.440	0.425	0.232	1810.08	0.050	L 923

SPECIAL STRUCTURAL STATIONS

STATION	X FROM THROAT (IN)	RADIUS TO LINER SURFACE (IN)	L NUMBER OF X
9	21.046	45.899	L 931
12	176.243	96.822	L 933

MATERIAL CODES REFER TO STRUCTURAL MATERIALS TABLE ON NEXT PAGE

BASE

NOZZLE STRUCTURAL DESIGN (PAGE 2) STRUCTURAL MATERIALS

STRUCTURAL MATERIALS

CODE	NAME	DENSITY (LB/IN**3)	MODULUS (PSI)	DESIGN STRENGTH (PSI)	COMPRESSIVE YIELD STRENGTH (PSI)	POISSONS RATIO	L NUMBER OF DENSITY
1	MARAGING STEEL	0.2370	27000000.	215000.	200000.	0.30	L 935
2	180,000 ULTIMATE STEEL	0.2830	29000000.	180000.	179000.	0.30	L 940
3	90,000 ULTIMATE STEEL	0.2830	29000000.	90000.	70000.	0.30	L 945
4	6AL-4V TITANIUM	0.1600	16500000.	160000.	155000.	0.31	L 950
5	7075-T652 ALUMINUM	0.1010	10500000.	70000.	63000.	0.33	L 955
6	STRUCTURAL FIBERGLASS	0.0700	4000000.	50000.	45000.	0.25	L 960
7	BERYLLIUM	0.0660	42500000.	40000.	30000.	0.30	L 965
8	MOLYBDENUM	0.3680	47000000.	90000.	90000.	0.30	L 970
9	COLUMBIUM	0.3100	15000000.	40000.	40000.	0.30	L 975
10	304 STAINLESS STEEL	0.2860	28000000.	125000.	55000.	0.30	L 980
11	17-7 PH STEEL	0.2760	29000000.	170000.	75000.	0.30	L 985
12		0.0	0.	0.	0.	0.0	L 990
13		0.0	0.	0.	0.	0.0	L 995
14		0.0	0.	0.	0.	0.0	L 1000
15		0.0	0.	0.	0.	0.0	L 1005
16		0.0	0.	0.	0.	0.0	L 1010
17		0.0	0.	0.	0.	0.0	L 1015
18	FLEXIBLE SEAL ELASTOMER	0.0470	30.(SHEAR)	500.(SHEAR)	--------------	0.4998	L 1020

(L NUMBERS ARE CONSECUTIVE FROM LEFT TO RIGHT)

HONEYCOMB MATERIALS

19 HONEYCOMB CORE 20.00000 L 1061

20 FLAG USED IF DESIGNATING HONEYCOMB IN STRUCTURAL SHELL TABLE ON PREVIOUS PAGE (IF SHELL CODE IS 20, HONEYCOMB IS USED)

	CODE(ABOVE TABLE)	L NUMBER OF FACING CODE STORAGE LOCATION
INNER HONEYCOMB FACING	6.	L 1063
OUTER HONEYCOMB FACING	[illegible]	L 1064

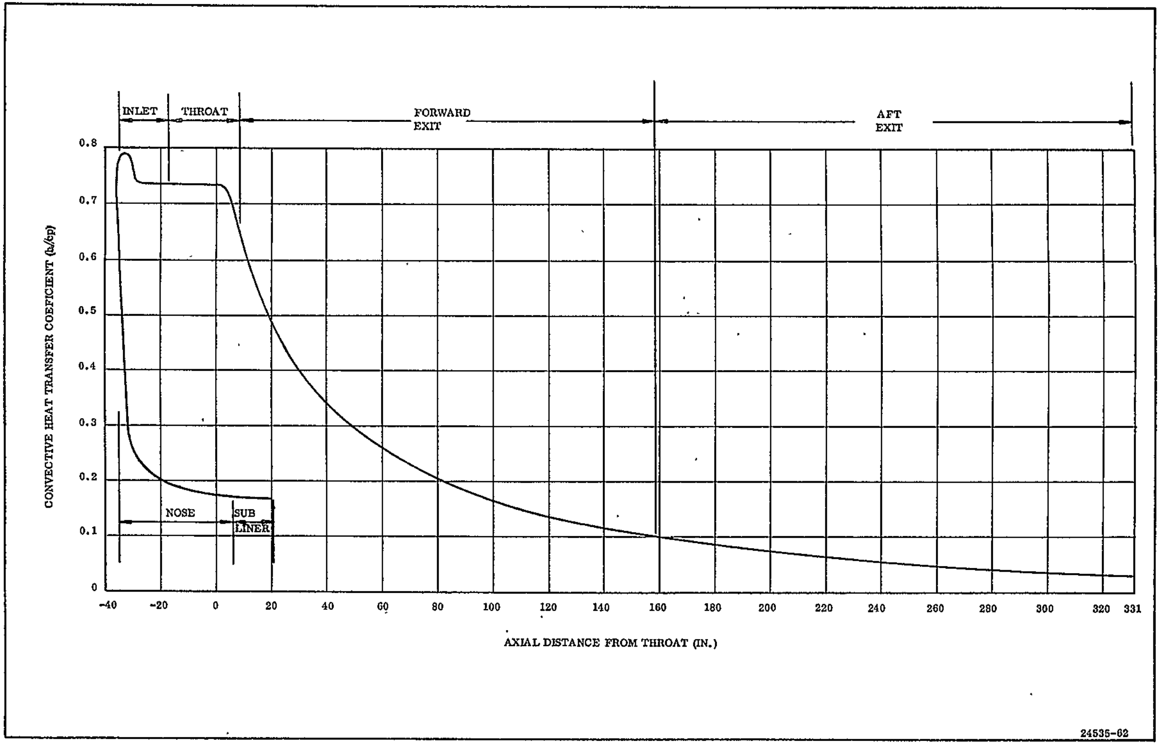


Figure 248. 260 In. Convective Heat Transfer Coefficient vs Axial Location (Carbonaceous Wall)

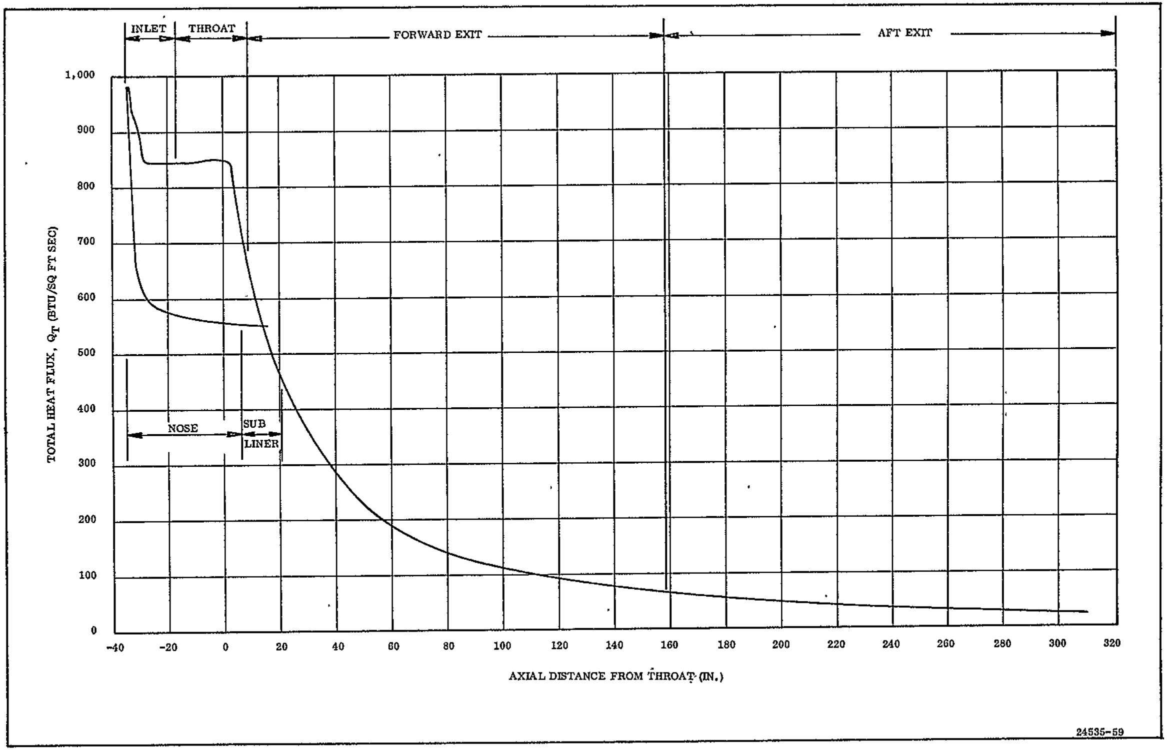


Figure 249. 260 In. Total Heat Flux vs Axial Location (Asbestos Wall)

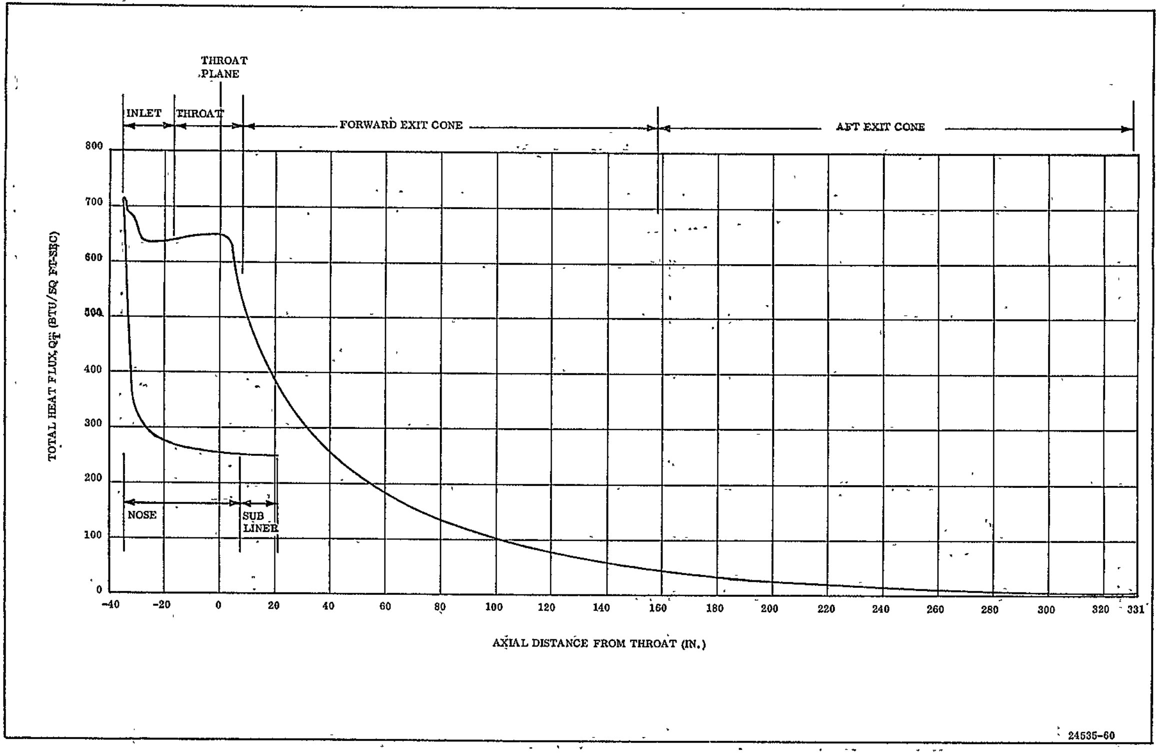


Figure 250. 260 In. Total Heat Flux vs Axial Location (Silica Wall)

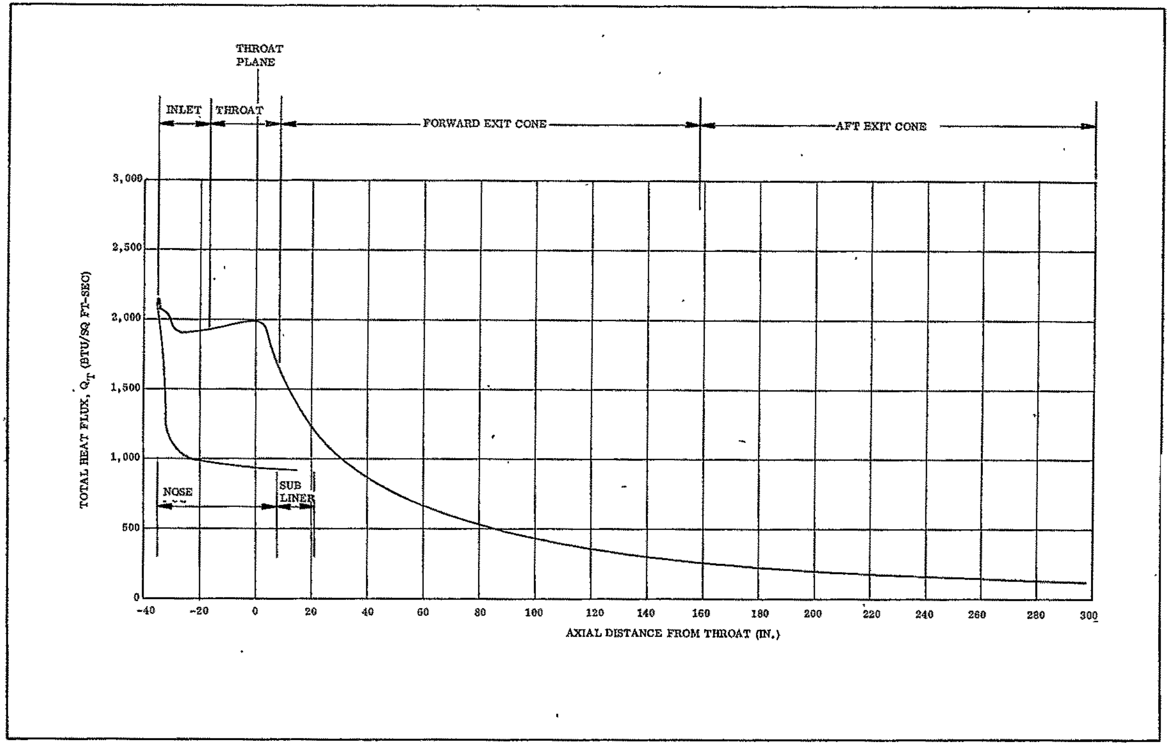


Figure 251. 260 In. Total Heat Flux vs Axial Location (Paper-Canvas Wall)

TABLE 68

260 IN. LOW COST MATERIAL EROSION-CHAR RATES

Submerged Liner		Nose		Inlet Ring		Throat		Forward Exit Cone		Aft Exit Cone	
Erosion Rate (mils/sec)	Char Rate (mils/sec)	Erosion Rate (mils/sec)	Char Rate (mils/sec)	Erosion Rate (mils/sec)	Char Rate (mils/sec)	Erosion Rate (mils/sec)	Char Rate (mils/sec)	Erosion Rate (mils/sec)	Char Rate (mils/sec)	Erosion Rate (mils/sec)	Char Rate (mils/sec)
		FM-5272		SP-8030-96		SP-8030-96				MXS-198	
		33.2	1.30	29.7	3.3	27.0	3.0	--	--	3.5	5.2
KF-418		KF-418						KF-418		FM-5272	
9.7	2.7	37.0	3.7					29.5	3.5	4.0	0.50
23-RPD				SP-8057		LCCM-2626		SP-8057		KF-418	
10.8	2.4			14.2	5.4	15.10	13.04	11.85	5.75	2.75	2.75
FM-5272				LCCM-2626		SP-8050					
7.0	2.8			16.2	12.85	10.63	7.67				
MXA-6012		SP-8057		WB-8217		MX-4926				LCCM-4120	
13.7	2.5	14.20	5.40	11.58	4.42	10.92	4.38			0	8.56
		WB-8217						SP-8050			
		11.56	4.44					9.59	7.91		

TABLE 69

260 IN. NOZZLE AND COMPONENT WEIGHT SUMMARY

Structure Steel Weights (lb)

Location	Standard Base Line Nozzle	Low Cost Material Nozzle No. 1	Low Cost Material Nozzle No. 2	Low Cost Material Nozzle No. 3	Low Cost Material Nozzle No. 4
9 Flange Steel	487	527	538	609	551
5-7 Throat Steel	1, 390	1, 387	1, 422	1, 422	1, 401
7-9 Forward Exit Steel	667	676	693	720	677
9-12	4, 999	5, 022	5, 059	5, 088	5, 027
12-15 Sandwich Aft Exit	1, 810	1, 811	1, 818	1, 799	1, 815
Subtotal	9, 353	9, 423	9, 530	9, 635	9, 471

Liner-Reinforced Plastic Weights (lb)

		Standard Base Line Nozzle Liner	Standard Base Line Nozzle Backup	No. 1 Liner	No. 1 Backup	No. 2 Liner	No. 2 Backup	No. 3 Liner	No. 3 Backup	No. 4 Liner	No. 4 Backup
Submerged Liner	1-2	317	0	383	0	515	0	665	0	812	0
Nose	3-4	1, 106	0	1, 961	0	4, 552	0	3, 681	0	2, 167	0
Inlet	4-5	1, 777	1, 445	1, 940	1, 305	3, 626	430	3, 140	518	2, 092	863
Throat	5-7	1, 120	2, 294	1, 146	2, 367	2, 455	1, 148	2, 541	1, 331	1, 336	1, 597
Forward Exit	7-14	6, 569	1, 227	6, 952	1, 201	7, 276	1, 014	12, 344	922	7, 549	845
Aft Exit	14-15	4, 611	3, 168	3, 409	5, 101	6, 588	2, 460	2, 463	6, 764	6, 094	2, 330
	Subtotal	23, 627		25, 766		30, 064		34, 369		25, 918	
	Total Nozzle Weight	32, 875		35, 190		39, 594		44, 004		35, 389	

NOTE: Of the five designs, the Standard Base Line Nozzle and Nozzle No. 1 received the greatest level of design effort.

TABLE 70

COST/PERFORMANCE EFFECTIVENESS OF FIVE FULL SCALE NOZZLE ASSEMBLY DESIGNS

Nozzle Design	Total Cost ($)	Total Weight (lb)	Cost/Lb ($)	Cost Change (%)	Weight Change (%)	Cost/Performance Index
Standard (Baseline)	1,296,807	32,875	39.45	--	--	100.00
Nozzle 1	1,183,888	35,190	33.64	-8.7	+6.6	96.39
Nozzle 2	933,972	39,594	23.59	-28.0	+20.4	88.00
Nozzle 3	863.635	44,004	19.63	-33.4	+33.8	88.83
Nozzle 4	1,179,795	35,389	33.34	-7.6	+7.6	96.38

TABLE 71

STANDARD BASELINE NOZZLE

I. COST

A.	MATERIALS (Table 72)	$ 345,184.00
B.	NOZZLE SHELL	
	9,352 lb Machined Steel at $20.00/lb	$ 187,060.00
C.	LABOR	
	33,000 hr at $10.00/hr	$ 330,000.00
D.	MATERIALS CONTINGENCY FOR HYDROCLAVE CURE (10%)	$ 34,518.00
E.	FACILITIES	
	Hydroclave $2,000,000.00	
	Tape Wrapper 275,000.00	
	Total $2,275,000.00	
	Amortized at six nozzles per year for 5 yr	$ 75,800.00
F.	TOOLING AND HANDLING EQUIPMENT	
	Tape Wrap Mandrels (4) $382,353.00	
	Handling and Insp Equip 382,353.00	
	Total $764,706.00	
	Amortized at six nozzles per year for 5 yr	$ 25,500.00
G.	BURDEN	$ 299,263.00
H.	GRAND TOTAL	$1,296,807.00

II. WEIGHT

A.	STEEL	9,352 lb
B.	PLASTIC	23,523 lb
	TOTAL NOZZLE WEIGHT	32,875 lb

TABLE 72

NASA 260 IN. NOZZLE COST EFFECTIVENESS
(Standard Nozzle)

Nozzle Location	Description	Total Material Required (incl scrap factor)[a]	Total Cost
Submerged OD	Liner	MX-2600 Warp 412 lb at $6.50/lb	$ 2,680
Nose	Liner	MX-4926 Warp 1,438 lb at $19.00/lb	27,332
Inlet	Liner	MX-4926 Warp 2,310 lb at $19.00/lb	43,890
	Backup	MXB-6001 Warp 1,878 lb at $3.50/lb	6,573
Throat	Liner	MX-4926 Bias 1,624 lb at $21.00/lb	34,104
	Backup	MX-2600 Warp 529 lb at $6.50/lb	3,438
	Backup	MXB-6001 Warp 2,453 lb at $3.50/lb	8,586
Fwd Exit	Liner	MX-4926 Warp 8,540 lb at $19.00/lb	162,260
	Backup	MXB-6001 Warp 1,595 lb at $3.50/lb	5,583
Aft Exit	Liner	MX-2600 Warp 5,994 lb at $6.50/lb	38,961
	Backup	MXB-6001 Warp 4,118 lb at $3.50/lb	14,413
			$345,184

[a]Scrap factor is 30% for warp tape, 45% for bias tape

TABLE 73

NOZZLE NO. 1 COST AND WEIGHT BREAKDOWN

I.	COST			
	A.	MATERIALS (Table 74)		$ 354,223.00
	B.	NOZZLE SHELL		
		9,423 lb Machined Steel at $20.00/lb		$ 188,460.00
	C.	LABOR		
		30,000 hr at $10.00/hr		$ 300,000.00
	D.	FACILITIES		
		Autoclave	$1,000,000.00	
		Tape Wrapper	275,000.00	
		Total	$1,275,000.00	
		Amortized at 6 nozzles per year for 5 yr		$ 42,500.00
	E.	TOOLING AND HANDLING EQUIPMENT		
		Tape Wrap Mandrels (4)	$382,353.00	
		Handling and Insp Equip	382,353.00	
		Total	$764,706.00	
		Amortized at 6 nozzles per year for 5 yr		$ 25,500.00
	F.	BURDEN		$ 273,205.00
	G.	GRAND TOTAL		$1,183,888.00
II.	WEIGHT			
	A.	STEEL STRUCTURE WEIGHT		9,423 lb
	B.	PLASTIC WEIGHT		25,406 lb
		TOTAL NOZZLE WEIGHT		35.190 lb

TABLE 74

NASA 260 IN. NOZZLE COST EFFECTIVENESS
(Low Cost Nozzle No. 1)

Nozzle Location	Description	Total Material Required (incl scrap factor)[a]	Total Cost
Submerged OD	Liner	FM-5272 Warp 498 lb at $2.00/lb	$ 996.00
Nose	Liner	WB-8217 Warp 2,549 lb at $20.97/lb	53,453.00
Inlet	Liner	WB-8217 Warp 2,522 lb at $20.97/lb	52,886.00
	Backup	MXB-6001 Warp 1,697 lb at $3.50/lb	5,939.50
Throat	Liner	MX-4926 Bias 1,662 lb at $21.00/lb	34,902.00
	Backup	MX-2600 Warp 819 lb at $6.50/lb	5,323.50
	Backup	MXB-6001 Warp 2,258 lb at $3.50/lb	7,903.00
Fwd Exit	Liner	SP-8050 Warp 9,038 lb at $17.50/lb	158,165.00
	Backup	MXB-6001 Warp 1,561 lb at $3.50/lb	5,463.50
Aft Exit	Liner	KF-418 Warp 4,432 lb at $1.35/lb	5,983.00
	Backup	MXB-6001 Warp 6,631 lb at $3.50/lb	23,208.50
			$354,223.00

[a]Scrap factor is 30% for warp tape, 45% for bias tape

TABLE 75

NOZZLE NO. 2 COST AND WEIGHT BREAKDOWN
(Segmented)

I.	COST		
	A. MATERIALS (Table 76)		$160,370.00
	B. NOZZLE SHELL		
	9,530 lb Net Machined Steel at $20.00/lb		$190,600.00
	C. LABOR		
	30,000 hr at $10.00/hr		$300,000.00
	D. FACILITIES		
	Autoclave	$1,000,000.00	
	Tape Wrapper	275,000.00	
	Total	$1,275,000.00	
	Amortized at 6 nozzles per year for 5 yr		$ 42,500.00
	E. TOOLING AND HANDLING EQUIPMENT		
	Tape Wrap Mandrels (3)	$286,764.00	
	Segmented Molds (8)	80,000.00	
	Handling and Insp Equip	382,353.00	
	Total	$749,117.00	
	Amortized at 6 nozzles per year for 5 yr		$ 24,970.00
	F. BURDEN		$215,532.00
	G. GRAND TOTAL		$933,972.00
II.	WEIGHT		
	A. STEEL STRUCTURE WEIGHT		9,530 lb
	B. PLASTIC WEIGHT		30,064 lb
	TOTAL NOZZLE WEIGHT		39,594 lb

TABLE 76

NASA 260 IN. NOZZLE COST EFFECTIVENESS
(Low Cost Nozzle No. 2)

Nozzle Location	Description	Total Material Required (incl scrap factor)[a]	Total Cost
Submerged OD	Liner	KF-418 Warp 670 lb at $1.35/lb	$ 905.00
Nose	Liner	KF-418 Warp 5,918 lb at $1.35/lb	7,989.00
Inlet	Liner	LCCM-2626 3,807 lb at $0.75/lb	2,855.00
	Backup	KF-418 Warp 559 lb at $1.35/lb	755.00
Throat	Liner	LCCM-2626 2,578 lb at $0.75/lb	1,934.00
	Backup	KF-418 Warp 615 lb at $1.35/lb	830.00
	Backup	KF-418 Warp 1,031 lb at $1.35/lb	1,392.00
Fwd Exit	Liner	SP-8057 Warp 9,459 lb at $14.00/lb	132,426.00
	Backup	KF-418 Warp 1,318 lb at $1.35/lb	1,779.00
Aft Exit	Liner	LCCM-4120 6,917 lb at $0.75/lb	5,188.00
	Backup	KF-418 Warp 3,198 lb at $1.35/lb	4,317.00
			$160,370.00

[a]Scrap factor is 30% for warp tape, 45% for bias tape, 5% for molding compounds

TABLE 77

NOZZLE NO. 3 COST AND WEIGHT BREAKDOWN

I.	COST	
A.	MATERIALS (Table 78)	$103,635.00
B.	NOZZLE SHELL	
	9,635 lb Net Machined Steel at $20.00/lb	$192,700.00
C.	LABOR	
	30,000 hr at $10.00/hr	$300,000.00
D.	FACILITIES	
	Autoclave $1,000,000.00	
	Tape Wrapper 275,000.00	
	Total $1,275,000.00	
	Amortized at 6 nozzles per year for 5 yr	$ 42,500.00
E.	TOOLING AND HANDLING EQUIPMENT	
	Tape Wrap Mandrels (4) $382,353.00	
	Handling and Insp Equip 382,353.00	
	Total $764,706.00	
	Amortized at 6 nozzles per year for 5 yr	$ 25,500.00
F.	BURDEN	$199,300.00
G.	GRAND TOTAL	$863,635.00
II.	WEIGHT	
A.	STEEL STRUCTURE WEIGHT	9,635 lb
B.	PLASTIC WEIGHT	34,369 lb
	TOTAL NOZZLE WEIGHT	44,004 lb

TABLE 78

NASA 260 IN. NOZZLE COST EFFECTIVENESS
(Low Cost Nozzle No. 3)

Nozzle Location	Description	Total Material Required (incl scrap factor)[a]	Total Cost
Submerged OD	Liner	23-RPD Warp 865 lb at $4.25/lb	$ 3,676.00
Nose	Liner	FM-5272 Warp 4,785 lb at $2.00/lb	9,570.00
Inlet	Liner	SP-8030-96 Warp 4,082 lb at $4.90/lb	20,002.00
	Backup	KF-418 Warp 673 lb at $1.35/lb	909.00
Throat	Liner	SP-8030-96 Bias 3,684 lb at $6.90/lb	25,420.00
	Backup	KF-418 Warp 615 lb at $1.35/lb	830.00
	Backup	KF-418 Warp 1,210 lb at $1.35/lb	1,634.00
Fwd Exit	Liner	KF-418 Warp 16,047 lb at $1.35/lb	21,700.00
	Backup	KF-418 1,199 lb at $1.35/lb	1,619.00
Aft Exit	Liner	FM-5272 Warp 3,202 lb at $2.00/lb	6,404.00
	Backup	KF-418 Warp 8,793 lb at $1.35/lb	11,871.00
			$103,635.00

[a] Scrap factor is 30% for warp tape, 45% for bias tape

TABLE 79

NOZZLE NO. 4 COST AND WEIGHT BREAKDOWN

I.	COST		
	A.	MATERIALS (Table 80)	$ 351,653.00
	B.	NOZZLE SHELL	
		9,471 lb Net Machined Steel at $20.00/lb	$ 189,420.00
	C.	LABOR	
		30,000 hr at $10.00/hr	$ 300,000.00
	D.	FACILITIES	
		Autoclave $1,000,000.00	
		Tape Wrapper 275,000.00	
		Total $1,275,000.00	
		Amortized at 6 nozzles per year for 5 yr	$ 42,500.00
	E.	TOOLING AND HANDLING EQUIPMENT	
		Tape Wrap Mandrels (4) $382,353.00	
		Handling and Insp Equip 382,353.00	
		Total $764,706.00	
		Amortized at 6 nozzles per year for 5 yr	$ 25,600.00
	F.	BURDEN	$ 272,722.00
	G.	GRAND TOTAL	$1.179,795.00
II.	WEIGHT		
	A.	STRUCTURE STEEL WEIGHT	9,471 lb
	B.	PLASTIC WEIGHT	25,918 lb
		TOTAL NOZZLE WEIGHT	35,389 lb

TABLE 80

NASA 260 IN. NOZZLE COST EFFECTIVENESS
(Low Cost Nozzle No. 4)

Nozzle Location	Description	Total Material Required (incl scrap factor)[a]	Total Cost
Submerged OD	Liner	MXA-6012 Warp 1,056 lb at $1.85/lb	$ 1,954.00
Nose	Liner	SP-8057 Warp 3,120 lb at $14.00/lb	43,680.00
Inlet	Liner	SP-8057 Warp 2,720 lb at $14.00/lb	38,080.00
	Backup	KF-418 Warp 1,122 lb at $1.35/lb	1,515.00
Throat	Liner	SP-8050 Bias 1,937 lb at $19.50/lb	37,772.00
	Backup	KF-418 Warp 615 lb at $1.35/lb	830.00
	Backup	KF-418 Warp 1,615 lb at $1.35/lb	2,180.00
Fwd Exit	Liner	SP-8050 Warp 9,814 lb at $17.50/lb	171,745.00
	Backup	KF-418 Warp 1,099 lb at $1.35/lb	1,484.00
Aft Exit	Liner	MXS-198 Warp 7,922 lb at $6.10/lb	48,324.00
	Backup	KF-418 Warp 3,029 lb at $1.35/lb	4,089.00
			$351,653.00

[a] Scrap factor is 30% for warp tape, 45% for bias tape

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